THE CARBONIFEROUS SEQUENCE IN THE WERRIE BASIN.

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With Palaeontological Notes by Ida A. Brown, D.Sc.

(Plate xviii; five Text-figures.)

[Read 24th November, 1937.]

This paper is a sequel to papers already published on the geology of the Werrie Basin or Syncline (Carey, 1934*a*, 1934*b*, 1935; Walkom, 1935). The field work upon which all the papers are based was carried out during the years 1932–4 while the writer was Deas-Thomson Scholar and Science Research Scholar of the University of Sydney. Professor W. R. Browne accompanied the writer in the field on several occasions and has always been ready to discuss the problems that have arisen.

Removal of the author to New Guinea on field-service in the latter part of 1934 has delayed publication. The paper has been prepared in Papua, which has entailed the handicap of great restriction of available literature, but in compensation the writer has been able to profit by the wide experience of Mr. J. N. Montgomery, his senior officer in the Oil Search Ltd. Geological Survey.

In the field area the writer met kindness on all sides, and reference has been made in previous papers to many whose hospitality has been outstanding. The stratigraphical work recorded in this paper was chiefly carried out with the courtesy and hospitality of Mr. and Mrs. Eugene McCarthy of Currabubula, Mr. and Mrs. Bruce Adams and family of "Woodlands", Mr. and Mrs. H. J. Perfrement and Mr. Tom Perfrement of "Merlewood", and Mr. and Mrs. Arnold Perfrement and family of "Royston". The fossil collecting work was much aided by various residents of the district, who joined the writer in collecting expeditions. Among these Mr. Eugene McCarthy, Mr. Tom Perfrement, Mr. Tom Creek, and Mr. Ray Swain of "Melrose", Carrol, may be specially mentioned. Thanks are also due to Mr. H. W. Ison of Currabubula, whose well-known willingness to help others has on very many occasions facilitated transport in the carrying out of this work.

A departure from the usually accepted nomenclature for the divisions of the Carboniferous strata is incorporated in the paper. For the present the name Burindi is retained for the marine series forming the lower part of the sequence, but the original Kuttung Series is divided into a Lower and an Upper Kuttung Series. This change has been necessitated by the discovery of Viséan fossils in the lower half of the Kuttung succession. The stratigraphical implications of this discovery, which are of some importance, it is hoped to discuss shortly in another paper.

A. Stratigraphical Sections of the Carboniferous Rocks of the Werrie Basin.

1. The Woodlands Section.

The Woodlands section is admirably situated for the examination of the Kuttung series as developed on the eastern limb of the Werrie syncline.

From the Werrie basalts on Anstey's Creek in the Parish of Currabubula, the section-line follows the south boundary of portions 74, 275, 259, 258, and 159 (see Text-fig. 1). The line was not followed further east through the Burindi Series, owing to extensive cultivation and poorness of outcrops.

The highest outcrop of the Burindi beds is found in the second small gully on the road between Woodlands and Glenarvon homesteads, which follows the section-line east of the Currabubula Creek crossing. Here olive-green mudstones are found with numerous dwarfed fossils.

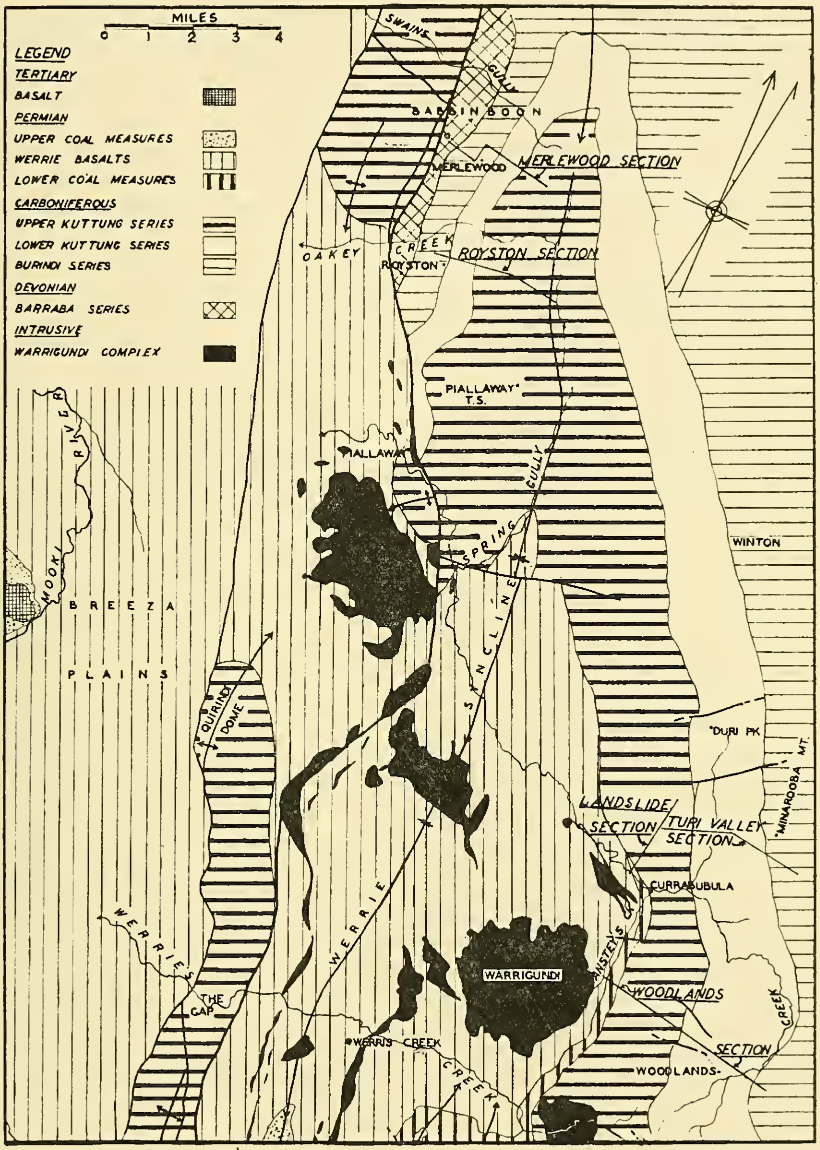
Following the Burindi beds, the base of the Kuttung is concealed under a soil cover. In portion 169, about a mile north of the section line, however, the abundance of shed boulders in the cultivation paddocks indicates that a conglomerate is probably developed there at the base of the series. Next are pebbly and sandy tuffs with interbedded sandy shales. One band of the latter is packed with *Rhodea*-like remains chiefly belonging to the *Sphenopteris* group, and among these are suspected to be some new types. *Lepidodendron Veltheimianum*, *Stigmaria ficoides* and *Sphenopteridium* (?) are present.

Between this plant-horizon and the main pyroxene-andesite at Woodlands homestead are well-bedded sandy felspathic tuffs of buff, brown, and chocolate colour. Scattered pebbles of granite, aplite and chert, and pebbly bands, are not infrequent. The tuffs are typically barren, but odd plant-stems are met with, as well as occasional zones packed with macerated carbonaceous material. As the pyroxene-andesite is approached the conglomeratic phase becomes more abundant, and close below the andesite there is a very coarse boulder-bed resting on finer tuffs.

A good exposure of this horizon is to be seen near "Woodlands" homestead a little south of the section-line, where the andesite crosses Currabubula Creek (Portion 44). Here the gritty tuff is followed by ten feet of fine tuff with pebbles, then fifteen feet of conglomerate, becoming coarser upwards, then ten feet of gritty tuff, overlain by about twenty feet of coarse conglomerate with boulders up to two feet in diameter. This is followed by pebbly tuff, then a band of conglomerate, overlain by about fifteen feet of dark chocolate gritty tuff which forms the bed for the andesite flow. Even the coarsest of the conglomerate is crudely bedded, and the boulders are well rounded and without recognizable glacial striae. Granitic rocks are abundant among the boulders, but the largest are porphyritic andesite, with a Devonian lithology (e.g., as in the Barraba Series in the Babbinboon district) rather than the andesites indigenous to the Kuttung Series.

The total thickness of Kuttung rocks below the pyroxene-andesite is nearly 200 feet. Where the section-line crosses it the andesite flow is 600 feet thick. Following the lava are about 2,300 feet of pebbly and gritty felspathic tuffs with occasional conglomeratic horizons. Among the colluvial debris from these beds petrified fragments of *Pitys* are common.

At the top of the Lower Kuttung Series is a discontinuous horizon of pyroxene-andesite flows, of which Duri Peak and Kingsmill Peak are prominent outcrops. On the Woodlands section is a mass of andesite 800 feet thick on this horizon. As with the lower flow, a bouldery conglomerate is developed immediately below the extrusive rock.



Text-fig. 1.—Geological Map of part of the Werrie Basin showing Section-lines and Localities referred to in the text.

The coarse boulder bed which follows the upper pyroxene-andesite zone is the basal conglomerate of the Upper Kuttung Series. Three stages are recognizable: the Lower Glacial, 2,500 feet thick; the Interglacial, 1,000 feet thick; and the Upper Glacial, 1,500 feet thick, making a total thickness of 5,000 feet.

In the basal conglomerate of the Lower Glacial Stage the boulders, which range up to three feet in diameter, are mainly igneous types, such as granites, both acid and intermediate, pink porphyries with an aplitic appearance, and porphyrites, but few of the types are such as are likely to have been derived from the erosion of the volcanic rocks of the Lower Kuttung. There is no obvious stratification or sorting, but no glacial striae were recognized. Upwards they become less bouldery and have a deep purple matrix.

Overlying the coarse conglomerates is a thick series of gritty tuffs. Pebbly and conglomeratic bands of a glacial facies become more numerous as the series is ascended, finally grading into tillites about 900 feet above the base of the stage. The pebbles present a wide variety of types, with a range of fresh igneous rocks, both plutonic and effusive, as well as limestone, chert, quartz, phyllite and schist.

The ensuing glacial beds are at first mostly true tillite, with bands of glacial grits and fluvio-glacial conglomerate. In the tillite the pebbles weather uniformly with the matrix and cannot readily be detached, but striated pebbles were dug out from the conglomerates.

The tillites pass up into varves. They are beautifully laminated, with frequent contemporaneous contortions and abundant erratics. This zone is considered to be the equivalent of the Glenoak varve horizon near Seaham (Osborne, 1922, p. 180). Coloured laminated tuffs follow the varves, and these are associated with fine-grained beds which have yielded some interesting carbonized petrifactions, including the type specimen of *Samaropsis ovalis* (Walkom, 1935, p. 460).

Overlying the plant-bearing tuffs is a mass of fluvio-glacial conglomerate, 300 feet in thickness. The pebbles, which are similar to those in the earlier conglomerates, but with a greater prevalence of acid lavas which may have originated within the Kuttung, are well rounded, and vary up to a foot in major diameter. Nearly every pebble shows glacial striae or deep grooves.

The deposition of this conglomerate mass was succeeded by a further advance of the glacier and the deposition of varves. The latter are rather coarse, tending towards varve-sandstones, especially near the top. This set of varves represents the culmination of the lower glacial advance, for they are rapidly followed by *Rhacopteris*-bearing grits which initiate the tuffs of the Interglacial Stage.

The Interglacial Stage is one of the most resistant physiographic units in the Werrie region, and its cliffs and bluffs always tower above the strike-valleys of the Lower Kuttung. Immediately above the *Rhacopteris* tuff at the base is the pebbly phase of hard white felspathic grit which makes up the bulk of the stage. Then comes about 100 feet of soda-rhyolite tuff. This bed shows considerable lithological variation from a fine-grained green cherty type to a coarse phase with fragments of quartz, felspar, and green felsite, which grades further into flow-breccia. Overlying the green alkaline tuffs is a bed of well-graded breccia. It consists mainly of angular chips of quartz-felsite a little larger than peas. Upwards, this becomes finer and more conglomeratic, and then grades up into white *Rhacopteris*-bearing tuff at the top of the Interglacial Stage.

At the base of the Upper Glacial beds are a few feet of coarse conglomerate with boulders up to a foot in diameter. This conglomerate has a distinctly glacial aspect, and is followed by finer conglomerates which are clearly fluvio-glacial, above which is a thin bed of soda-rhyolite tuff, then a very thin felsite flow. Next are two plant-bearing horizons separated by tuffs and varves. Seeds of the *Cordaicarpus* type have been collected from the upper of the two plant horizons.

The top 800 feet of the Kuttung are largely glacial. Varves are best developed in the upper part of this section and are underlain by tillite. The remainder is partly fluvio-glacial, partly tillitic, and partly tuffaceous.

Resting directly on the Kuttung beds are the Greta Coal-Measures. The lowest bed is a strongly-cemented conglomerate with hard gritty bands. The latter contain abundant plant-impressions measuring up to two feet in length and three and a half inches across. Beneath the conglomerate are hard but fine-grained acid tuffs which are well laminated. These are the highest beds of the Kuttung or the lowest of the Greta Series, and they rest on a coarse fluvio-glacial conglomerate made up chiefly of pebbles derived from Kuttung lavas. The lithology of this formation is quite distinct from that of the Greta conglomerates.

2. TURI VALLEY SECTION.

The Turi Valley section is suitable for examining the Kuttung sequence from the Interglacial Stage to the Burindi Series, especially the Lower Glacial beds. The section commences on the Travelling Stock Route from Currabubula to Duri, where the Mount Minarooba pyroxene-andesite sill crosses the road. From this point the section-line runs west along the north boundary of portions 283 and 284 (Parish of Currabubula), then turns south along the west boundary of portion 284 to the north-east corner of portion 107. From this point the section follows a bearing of S.63°W. for about two miles, crossing the broad valley of Turi Creek, and ascending the scarp to the top of the cliffs which overhang the valley on the south-west.

The Minarooba sill, which is about 530 feet thick, intrudes the Burindi Series about 700 feet below the base of the Kuttung, and is on the same general horizon as the silicified zone in the Woodlands section, which marks the position underground of the lenticular intrusive sheet there.

The Burindi Series consists of the usual well-bedded, olive-green mudstones which are richly fossiliferous.

At the base of the Lower Kuttung Series, resting directly on the fossiliferous beds in portion 199 (Parish of Currabubula) adjacent to the section-line, are a number of impure coal-seams. In a gully a little above Mr. Howlett's house are at least four seams, the highest of which is about six feet thick on the outcrop, with a band twelve inches from the top. The unweathered seam is probably much thicker. Both the coal-seams and the Burindi mudstones on which they rest are much fractured and jointed by numerous minor dip-faults.

Benson (1920) included the coal-seams in the Burindi Series, but the present writer regards them as marking the base of the Kuttung, for it is at this horizon that the change in lithology from the typical Burindi mudstones to the gritty felspathic and keratophyric tuffs, which persist throughout the Lower Kuttung, takes place. The stratigraphical horizon relative to the main pyroxene-andesite flow is closely comparable with the base of the Kuttung on the Woodlands section. *Lepidodendron Veltheimianum*, *Stigmaria ficoides* and *Calamites* are frequent in the lower tuffs in much the same state of preservation as in the remainder of the Lower Kuttung.

Petrological descriptions of some of the tuffs have been given by Browne (1920).

The main pyroxene-andesite flow, here 860 feet thick, is about 1,100 feet above the base of the Kuttung. As in the Woodlands section, the lava is underlain by a thick mass of heavy conglomerate which is separated from the andesite by a bed of tuff. The boulders average about 10 inches in diameter, but frequently exceed a foot. *Pitys* in silicified blocks occurs in the lower part of this conglomerate, where it crosses the stock-route a little to the east of the section-line, and the underlying tuffs there yield *Lepidodendron Veltheimianum* and *Stigmaria ficoides.*

The top of the andesite is rather weathered, and is followed by about 20 feet of leached material containing white kaolinitic and carbonated material. This is followed by coarse conglomerate with boulders averaging from eight to ten inches, mostly granitic rocks and hornblende-porphyrite, with occasional pebbles of pyroxene-andesite. The conglomerate is rudely bedded, with some finer bands.

Between the main pyroxene-andesite and the horizon of the Duri Peak discontinuous zone are nearly four thousand feet of strata, mainly felspathic gritty tuffs with pebbly bands and occasional horizons of coarse conglomerate. About 700 feet above the andesite is a conglomerate with pebbles averaging four inches in diameter. In portion 10, roughly on this horizon, a little to the east of the section line, is a good collecting ground for *Stigmaria ficoides* and *Lepidodendron Veltheimianum.*

A thousand feet higher is another conglomerate, with pebbles about six inches in diameter, among which are a good many of pyroxene-andesite. About 600 feet of tuffs separate this from the next conglomerate horizon, where the pebbles are a little smaller.

Near the top of the Lower Kuttung is a stratiform sheet of basalt 100 feet thick. This may be a contemporaneous flow, but such a lava is not usual there. It may be an intrusive, referable to either the Warrigundi or the Tertiary cycle of volcanic activity.

Owing to the down-faulting of the south-eastern end of the Duri Peak andesite, and to its rapid lenticular thinning, the Turi Valley section takes very little account of this flow. Scattered along the strike, however, are numerous blocks of vesicular and scoriaceous andesite. The outcrop is not of the best and it is difficult to decide whether it is the thin tongue-end of the flow or the débris distributed beyond the end of the flow by contemporaneous erosion.

The Lower Glacial beds, which follow the Duri Peak andesite, are more than 3,000 feet thick. The basal conglomerate, which is about 200 feet thick, contains boulders up to two feet in diameter, chiefly of the characteristic granitic rocks and pink porphyries. Silicified remains of *Pitys* are abundant in the lower portion and in the immediately underlying tuff.

Above the conglomerate are about 800 feet of pebbly tuff and conglomerate which makes poor outcrop, and which grades upwards into a thick sequence of fluvio-glacial conglomerate, tillite, and varve, exactly as in the Woodlands section. In these beds erratics of pyroxene-andesite of Kuttung lithology are not uncommon and often exceed two feet in diameter. The more common granitic erratics are often more than a foot across. As before, this zone is separated from the striated-pebble horizon by bright green and red laminated tuffs. The 600-foot fluvio-glacial conglomerate which follows is almost entirely made up of striated pebbles, the hard argillites of the pebbles being particularly adapted to the preservation of the glacial grooves. Erratics of weathered granite up to twenty inches in diameter are also present. Interstratified with this conglomerate is a flow of hornblende-andesite about ten feet thick.

The fluvio-glacial conglomerate is followed by 250 feet of tuffs, then nearly 400 feet of varves, which are the highest member of the Lower Glacial Stage.

The conglomerates which follow, forming the scarp rim, are the basal strata of the Interglacial Stage. They are 100 feet thick, well-graded, and with little suggestion of glacial origin. Overlying them is a series of conglomerates, grits, and tuffs with plant-bearing beds. The late R. H. Cambage collected *Archaeo-*

calamites here. These beds are followed by the basal conglomerate of the Upper Glacial Beds, the sequence of which is described in the Landslide section.

3. LANDSLIDE SECTION.

The Landslide section which completes the Kuttung sequence through the Upper Glacial Stage, is complementary to the Turi Valley section, which traverses the beds below the Interglacial Stage.

The upper part of the Interglacial Stage, beneath the basal conglomerate of the Upper Glacial beds, consists of plant-bearing grits and tuffs with conglomeratic bands from which *Rhacopteris* and *Cordaites* have been collected. This sequence is nearly 400 feet thick and is injected by several thin keratophyre sills.

The coarse basal conglomerate of the Upper Glacial Stage is 90 feet thick. The boulders, which are well-rounded, average about six inches in diameter, with a maximum of fifteen inches, and include such rock-types as biotite-granite, quartzite and rhyolite. They have been derived for the most part from a pre-Carboniferous terrain.

The varves which follow are 300 feet thick. Contemporaneous contortions occur in the lower portions, and towards the top they become coarser and pass into varve-sandstones.

In the next 400 feet there is evidence of a lull in the glaciation, as the sediments are more normal in character, consisting mainly of conglomerates and tuffs. The conglomerates are well-graded and well-bedded, the average pebble-size being about two and a half inches. Lavas and felsites are most abundant among the pebbles, but keratophyre, porphyrite, rhyolite, limestone, and vein-quartz are also present. The interbedded sandy layers contain abundant carbonized and fragmental plant-material. The upper 200 feet of this Stage are made up almost entirely of creamy-white shales, probably largely tuffaceous in origin, which are packed with *Rhacopteris*. The instability of these beds on a steep dip-slope led to the landslide which gave the section its name.

Following these plant beds a glacial advance is recorded in 80 feet of fluviotill which grades into true tillite. The boulders, up to two feet in diameter, include hornblende-andesite, acid granite, biotite- and quartz-felsites, and rhyolite, as well as quartzite and limestone. The quartzo-felspathic matrix here and there develops a varvoidal structure in which the boulders are not infrequently big end up.

Above the fluviotill is a bold outcrop of soda-rhyolite tuff, 270 feet thick and very uniform in grainsize and lithology. This is at a very much higher horizon than the similar rock in the Interglacial Stage in the Woodlands section. It was the erroneous correlation of these two beds, and of the plant-bearing beds and glacial rocks of the Upper Glacial Stage of the Landslide section with the glacial beds, etc., of the Lower Glacial Stage of the Woodlands section, which led Benson (1920, pp. 307–8) to postulate a very heavy fault along Currabubula Creek (see Carey, 1934*a*, p. 368). There is a thin bed of soda-rhyolite tuff in the Upper Glacial Stage of the Woodlands section also, but it is not so prominent as in the Landslide section.

The alkaline tuff is followed by 1,000 feet of tillite, conglomerate, varve and tuff. This is exactly analogous to the sequence in the Woodlands section. The tillite is best developed in the lower 300 feet, and the varves are prominent at the top. The tillitic portion seems to have derived its boulders chiefly from a pre-Carboniferous landscape, whereas in the conglomeratic portions, both above and below the tillite, the pebbles are commonly felsites with other acid lavas which appear to have been derived from the Lower Kuttung Series.

The top member of the Kuttung is a 270-foot bed of conglomerate, identical with the rock occupying the same position in the Woodlands section. The pebbles are almost entirely of acid lavas derived from the erosion of the Kuttung. Toscanitic and dellenitic lavas with phenocrysts of quartz and biotite are the most numerous, with hornblende- and pyroxene-andesites less common; the felsites which dominate the conglomerates beneath them are still present but much rarer, while the rocks belonging to the granitic terrain of the tillites are almost entirely absent. The boulders average about six inches, with a maximum of about ten inches.

The total thickness of the Upper Glacial Stage in the Landslide section is about 2,750 feet.

4. ROYSTON SECTION.

The Royston section provides the most complete study of the Upper Kuttung rocks as they are developed in the western limb of the Werrie syncline. The section-line runs from the north-west corner of portion 46, Parish of Babbinboon, adjacent to 'Royston' homestead, and follows a bearing of N.79°E. to the point on the northern boundary of portion 48 in the Parish of Piallaway, where that boundary descends a cliff. From this point the section runs due east, following the northern boundaries of portions 48 and 49, and continuing within portion 59 as far as Oakey Creek.

This section commences at the western end on a thin bed of limestone in the fossiliferous mudstones of the Burindi Series. Five hundred feet above the limestone is a sheet of pyroxene-andesite thirty feet thick, which is presumed to be a sill. Between this andesite and the limestone, and also above the andesite, are several smaller lenses of the same igneous rock.

About 1,800 feet of strata intervene between the andesite sill (?) in the Burindi Series and the main pyroxene-andesite flow of the Lower Kuttung. Immediately underneath the flow are coarse conglomerates precisely as in the other sections. They are about 320 feet thick, with boulders up to four feet in diameter. The base of the Kuttung lies somewhere between the bottom of the conglomerates and the andesite sill (?). Assuming the constancy of the sill-horizon the thicknesses of strata involved are comparable with those in preceding sections.

The main pyroxene-andesite flow is 370 feet thick. It is mainly composed of the glassy phase (see p. 372), but spheroids of the lithoidal phase are very abundant in it.

Overlying the main pyroxene-andesite flow are 1,400 feet of pebbly felspathic tuffs which make up the rest of the Lower Kuttung. Many silicified fragments of *Pitys* shed from these strata have been found.

The basal conglomerate of the Upper Kuttung makes good outcrops, with boulders up to two feet in diameter. It is about 150 feet thick, and is followed by 200 feet of bedded tuffs, which are overlain by a thick series of varves. The varves have interbedded tuffaceous layers, and are followed by more tuffs which are interstratified with conglomerates rich in ice-scratched pebbles. This is the horizon which has yielded such fine glacial specimens elsewhere. Capping this tuff-glacial series and forming the top of the Lower Glacial Stage is a twenty-foot bed of hard tillite. The total thickness of the Lower Glacial Stage is about 1,000 feet.

The Interglacial Stage is about 1,200 feet thick. At the base are 220 feet of soda-rhyolite-tuff. The rest of the stage is made up of normal conglomerates and tuffs, with many plant-bearing horizons. The conglomerate at the base of the Upper Glacial Stage is not developed in the Royston section. Resting on the Interglacial Stage are 220 feet of varves, which are followed by 160 feet of hard, blue tuff which outcrops boldly as a line of cliffs. On top of this is a thin bed of creamy *Rhacopteris*-tuff, which has yielded, among other things, *Rhacophyllum*. Next come 370 feet of tuffs and fine conglomerates with a tillitic horizon at the top.

The acid lava which follows is characteristic of the western side of the Werrie syncline, though it is usually missing in the eastern limb. It contains phenocrysts of quartz, felspar and biotite, and is about 300 feet thick, becoming thicker to the east.

On top of the acid lava are 280 feet of varves. These are followed by a veneer of conglomerates and grits completing the section, which does not quite reach the top of the Upper Kuttung.

5. MERLEWOOD SECTION.

The Merlewood area has been mapped in rather more detail than other parts of the region, in order to determine clearly the relationship between the Lower Kuttung Series and the horizons of the fossiliferous marine beds which occur there.

The geological structure is shown in the map of the Babbinboon district (Plate xviii). Parallel belts of Carboniferous and Upper Devonian rocks dip conformably eastwards as part of the western limb of the Werrie syncline. To the east, the easterly dips continue beyond the limit of the map until the synclinal axis is reached. Westwards the area is bordered by three powerful faults where the imbricate Mooki thrusts emerge. The local trend of the strata is meridional, parallel to the thrusts, and the angle of dip varies between 25° and 50°, with the steeper dips to the west.

Two minor dip-faults have been found, but in either case the throw is less than 100 feet. There are three circular patches of basalt, which probably betoken necks, and a fourth outcrops a little beyond the northern limit of the map. A few basic dykes occur, trending in the dip-direction.

Topographically, the rocks of the Upper Kuttung Series form the high ground on the east and west, with an intermediate depressed belt, about two miles wide, where the Burindi and Devonian rocks lie. The surface forms are mature, with common development of cuestas and hog-back ridges.

Swain's Gully, which rises in portion 34, Parish of Babbinboon, and flows westwards through portions 14, 15, 62, 58, 16, 17, 36 and 25 of that parish, provides the most informative stratigraphical exposure in the district. It extends from the top of the main felspathic grit in the Upper Kuttung Series, across the Lower Kuttung with its marine horizon, through the Burindi beds to the Barraba Series.

Barraba Series.—The lowest beds exposed are well-jointed mudstones with the ribbon-like banding which is typical of this series. Quartz veins, which have not been encountered in the Carboniferous beds, are not uncommon here. As the Burindi Series is approached, the series becomes more and more bouldery, with rapidly increasing vulcanism, culminating in a very variable bed, about 800 feet in thickness, of what is best described as an agglomerate. Some phases are true conglomerates with well-worn boulders of andesitic lava, but elsewhere the matrix is entirely tuffaceous, and passes into rocks resembling flow-breccias. Finer interbedded tuff-partings near the upper part of this formation have yielded *Lepidodendron australe*. The series seems to reach its maximum coarseness at the top, immediately beneath the basal conglomerates of the Carboniferous. These quasi-volcanic conglomerates continue to the Tamworth–Gunnedah road which they cross near Carrol Gap, whence they have been traced for some distance to the north-west by A. C. Lloyd (1934).

Burindi Series.—Commencing this series is a basal conglomerate with boulders of granite, hornfels, and porphyrite measuring as much as ten inches in diameter. These are overlain by buff-coloured gritty sandstones with current-bedding and some conglomerate bands. The sandstones carry plant-stems, some of which resemble *Calamites*. This basal series is 400 feet thick and shows a progressive change in facies from the heavy conglomerates at the base to the sands and silts at the top. Next in the sequence are well-bedded dark blue marly mudstones and tuffs, which have yielded the fauna listed on page 352, including numerous specimens of *Cladochonus tenuicollis* and *Phillipsia* sp.

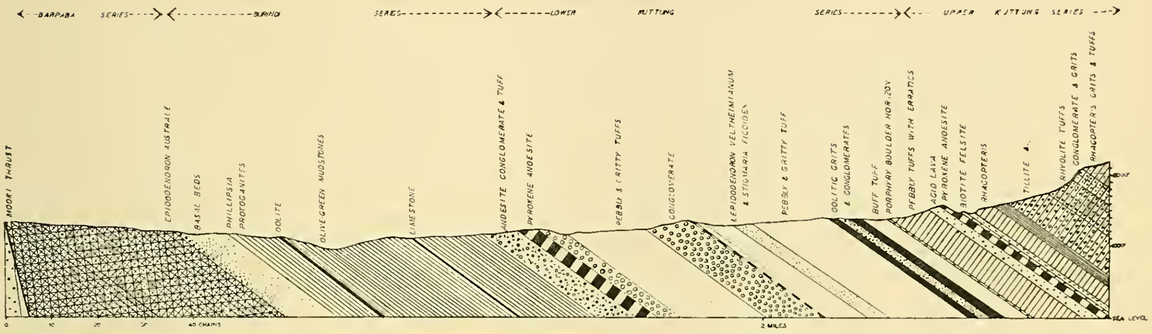
Following the marls are laminated olive-green mudstones of typical Burindi facies; about 200 feet above the base of these is a richly fossiliferous band, which is packed with fossils, including some low Lower Carboniferous forms, notably one closely resembling *Protocanites lyoni* M. & W. The forms are listed on page 352.

The Burindi Series is on the whole a remarkably uniform series of mudstones, with only occasional tuff-bands. Oolitic limestone is developed as discontinuous lenses on a horizon about 850 feet above the base, a horizon which has been picked up at intervals over a considerable distance. A typical exposure is to be seen in portion 64, Parish of Babbinboon. Crinoid ossicles, and occasional brachiopods and other fossils are found in the oolite. Limestone bands recur also about 2,000 feet above the base of the series, but these thin lenses are less persistent, and non-oolitic, and contain a good deal of pyrites, which may partially pseudomorph the fossils. The total thickness of the Burindi Series is more than 2,500 feet. Marine fossils and fragments of drift *Lepidodendron Veltheimianum* are quite numerous in the upper 1,000 feet.

Lower Kuttung Series.—The base of this series is exposed in the gully in the north of portion 15, close to the point where it crosses into portion 62. The lowest beds are tuffs and conglomerates 340 feet thick which contain *Lepidodendron Veltheimianum*. These are followed by a flow of pyroxene-andesite 200 feet thick, which thins out and disappears altogether in some places. Below the andesite, and along its strike where it is missing, are tuffaceous conglomerates in which the pebbles are pyroxene-andesite similar to the flow. Next follow 200 feet of coarse conglomerates. The boulders, which average about ten inches in diameter but reach as much as eighteen inches, are chiefly of pink granite and a hard porphyry which is resistant to weathering, together with grey quartzite and some volcanic rocks. Overlying these heavy conglomerates are 700 feet of pebbly and gritty tuffs. They are salmon- to buff-coloured on exposed surfaces and are fairly well bedded, with some pebbly layers and occasional plant-bearing horizons.

Above the gritty tuffs is another zone of coarse conglomerate 460 feet thick. Here the pink porphyry and acid granite are still present, as boulders up to two feet in diameter; there is, however, a greater proportion of volcanic rocks than on the lower horizon, especially a purple felsite in boulders as much as 14 inches in diameter.

Overlying this conglomerate are ten feet of reddish biotite-tuff, followed by another flow of pyroxene-andesite, where the section-line crosses it (see Plate xviii and Text-figure 2); this flow is only twenty feet thick but further south it increases to 300 feet. Above the lava is another 300 feet of pebbly and gritty tuffs, which is followed by 200 feet of rather more resistant grits bearing well-preserved impressions of *Lepidodendron Veltheimianum* and *Stigmaria ficoides*. Some of these plant-stems are very large, one piece of the former being ten inches in diameter and four feet in length. This specimen, portion of which is preserved in the Botany Museum at the University of Sydney, shows impressions which appear to be the lower parts of the leaves still attached to the stem. The plant-bearing bed is followed by another 650 feet of gritty tuffs, which continue until the *Amygdalophyllum-Lithostrotion* marine horizon is reached.



Text-fig. 2.—Merlewood Section.

On the line of section the marine horizon is very sparsely fossiliferous, and is represented by 270 feet of oolitic grits and conglomerates. The latter are markedly distinct from the other Lower Kuttung conglomerates. The pebbles are much smaller and more evenly sorted, and their lithology and ovoidal form are distinctive; grey quartzites and certain types of lava dominate. Northwards the oolitic zone passes laterally by progressive stages into grits and conglomerates without a perceptible oolitic matrix, but the types, size and system of sorting of the pebbles remain unchanged. A mile further north, in portion 60, richly fossiliferous limestones appear immediately overlying the grits and conglomerates, which here regain in part their oolitic character. *Amygdalophyllum* and *Lithostrotion* are by far the most abundant fossils, but by careful collecting a fairly extensive fauna of Viséan aspect has been obtained.

In view of the fact that this is the first record of marine strata from such a horizon in New South Wales, and that its implications are many and far-reaching, every precaution has been taken to ensure the accuracy of the field-work in the determination of their horizon. As a result it can confidently be stated that all possibility of these strata being infaulted Burindi beds has been eliminated, and it may be regarded as established that their horizon is high in the Lower Kuttung.

Following the oolitic and fossiliferous marine strata are buff-coloured gritty and pebbly tuffs with occasional boulders of granite and pink porphyry, some of which are as much as two feet in diameter. These beds are followed by a suite of volcanic rocks. The first flow is an acid-intermediate lava 140 feet thick. Next is a flow of pyroxene-andesite 90 feet thick, probably to be correlated with the Duri Peak andesite; then come 40 feet of biotite-felsite, and finally 70 feet of acid tuff. These lavas are regarded as the equivalents of Osborne's Volcanic Stage in the Lower Kuttung of the Lower Hunter Valley.

Upper Kuttung Series.—The lavas are followed by typical Lower Glacial Stage rocks, which are succeeded in turn by the tuffs of the Interglacial Stage. Unfortunately the coarse basal conglomerate of the Upper Kuttung is not present in this part of the area. However, it is well-developed in the Royston section, and a close correlation is possible between the rocks of the Interglacial Stage and the Lower Glacial Stage in the two sections.

Overlying the volcanic rocks are 230 feet of conglomerates, grits, and shales, with well preserved impressions of *Rhacopteris* and *Calamites*. These are followed by 150 feet of varves with interbedded tillite layers which yield striated pebbles.

Next comes a beautiful tillite. Here granite boulders, which are usually weathered, range in size up to three feet, and often rest big end uppermost. With them are large boulders of pyroxene-andesite, pink porphyries and rhyolites, and abundant pebbles of grey quartzite which bear well-preserved glacial striae, all of which are interbedded without much sorting in a dark chocolate matrix.

This glacial horizon, which is the top of the lower glacials, is followed by a varied series of soda-rhyolite tuffs, and other associated pyroclastics, with little detrital admixture. These pass into tuffaceous conglomerates and tuffs, which are in turn overlain by more acid tuffs and grits with *Rhacopteris*, which complete the section. The thickness of strata belonging to the Interglacial Stage is 860 feet, but this does not include the highest beds of that stage.

B. Palaeontological Notes. (I.A.B.)

Already a large number of forms (more than 80 species) have been recorded from this area by W. N. Benson (1921). Some have been described in detail, others are provisional determinations of Museum specimens.

At the time when Professor Benson's work was carried out no faunal zoning was possible, but he expressed the hope (1920, p. 370) that "as the detailed stratigraphical study of the Burindi Beds proceeds, accompanied by refined palaeontological work, a regular succession of faunal zones may be shown to exist in this State as elsewhere." The present work is an attempt at such zoning.

Exhaustive collections of the fauna were made by Mr. S. W. Carey from three horizons in the "Merlewood" section. Provisional determinations are given below; detailed descriptions of new and uncommon forms will be given in a later paper.

The lowest horizon is 400 feet stratigraphically above the base of the Burindi Beds, and consists of blue, marly mudstones and tuffs from which the following forms are identified: *Zaphrentis* sp., *Cladochonus tenuicollis* McCoy, Crinoid ossicles, *Fenestella* sp., (?) *Chainodictyon gigantea* Eth. ms., Brachiopod fragments, Gastropod fragments, *Phillipsia* sp.

Cladochonus tenuicollis McCoy is the most abundant fossil at this horizon. *Zaphrentis* is rare; it is a small form with a deep calice, showing about 36 septa in a section of 4 mm. diameter.

The second horizon, occurring about 200 feet stratigraphically above the first, contains a variety of specimens preserved in shales and limestone nodules. The following species are provisionally recognized:

Zaphrentis aff. *cliffordana* E. & H.
Zaphrentis sp.
Crinoid ossicles
Fenestella sp.
Schizophoria resupinata Martin
Chonetes sp. (cf. *hardrensis* Phill.)
Productus sp. (cf. *P. semireticulatus* Martin).
Productus sp.
Camarophoria (?) sp.
Dielasma sacculum var. *hastata* Sow.
Spirifer aff. *mosquensis* F. de W.

Spirifer cf. *bisulcatus* Sowerby
Spirifer striatus Sowerby
Spirifer striatus var. *attenuatus*
Reticularia lineata Martin
Reticularia sp.
Spathella sp.
Aviculopecten cf. *knockonniensis* McCoy
Aviculopecten (?) *granosus* de Kon.
Cardiopsis cf. *radiata* M. & W.
Nuculana sp.
Grammysia (?) sp.
Cardiomorpha sp.
Ptychomphalus culleni Dun & Benson
Mourlonia ornata Dun & Benson
Straparollus davidis Dun & Benson
Phanerotrema burindia Dun & Benson
Macrocheilus cf. *filosus* Sow.
Loxonema sp. (not *babbindoonensis*)
Protocanites cf. *lyoni* M. & W.
Glyphioceras (*Beyrichoceras*) (?)
Goniatite (?)

Most of the species have a relatively wide range within the Lower Carboniferous, but three forms are closely comparable, if not identical with *Zaphrentis cliffordana* Edwards and Haime, *Cardiopsis radiata* Meek and Worthen and *Protocanites lyoni* Meek and Worthen respectively, all of which occur in the Kinderhook Beds of the Lower Mississippian of North America (Grabau and Shimer, 1909; Worthen, 1866, p. 166). *Protocanites lyoni* also occurs in the basal beds of the Lower Carboniferous of Europe (H. Schmidt, 1923).

The faunal assemblage thus indicates that beds equivalent to the Tournaisian occur within the Burindi Series, but as yet there is insufficient evidence for more exact correlation. A careful study of the Productids and Spirifers may throw some light on the subject. Well preserved specimens of a Spirifer show some resemblances to *Spirifer* (*Choristites*) *mosquensis* Fischer de Waldheim, although direct comparison with available specimens of this Middle Carboniferous form from Moscow shows minor differences in ornamentation.

A third fossiliferous horizon occurring high in the Lower Burindi Series, near Currabubula, was described by W. N. Benson, who recorded the following forms (1920, p. 293):

Zaphrentis culleni Eth. fil.
Zaphrentis sp. indet.
Cactocrinus brownei Dun & Benson
Fenestella sp. indet.
Orthis (*Rhipidomella*) *australis* McCoy
Orthis (*Schizophoria*) *resupinata* Martin
Orthotetes (*Schellwienella*) *crenistria* Phill.
Productus longispinus Sow.
Chonetes cf. *hardrensis* Phill.
Dielasma sacculum var. *hastata* Sow.
Spirifer bisulcatus Sowerby
Spirifer sp. indet.
Spiriferina insculpta Phill.
Pelecypods spp. indet.
Conularia sp.
Phillipsia sp.

Another fossiliferous horizon in the "Merlewood" section is that of the limestone near the top of the Lower Kuttung, from which *Amygdalophyllum etheridgei* Dun and Benson was first obtained by Mrs. Scott (Benson, 1920, p. 341). It outcrops in Portion 60, in the north-east of the Parish of Babbinboon. Tentative determinations are as follow:

(?) *Symplectophyllum mutatum* Hill
Amygdalophyllum etheridgei D. & B.
Amygdalophyllum inopinatum Eth. fil.
Amygdalophyllum, sp. nov.
Aphrophyllum foliaceum Hill
Aphrophyllum, sp. nov.
Lithostrotion columnare Eth. fil.
Lithostrotion stanvellense Eth. fil.
Syringopora syrinx Eth. fil.
Michelinia sp. (cf. *M. dendroides* Hill)
Stromatoporoid
Fenestella sp.
Productus (?) *semireticulatus*
Spirifer cf. *mosquensis* F. de W.
Spirifer duplicicostatus Phill.
Spiriferina (?)

Camarophoria (?)
Reticularia lineata Martin
Reticularia sp.
Capulid (?)
Pleurotomarid (?)

The corals are preserved much better than the other forms and also give more definite indication of geological horizon. *Lithostrotion columnare* Eth. fil. is present in greatest abundance, although *Amygdalophyllum etheridgei* Dun and Benson is the only rugose coral previously recorded from this limestone horizon. Elsewhere in New South Wales there are occurrences of Lower Carboniferous corals within the Burindi Series. *Lithostrotion columnare* occurs at the Horton River and at Taree; *Lithostrotion stanvellense* occurs at Taree and at Hall's Creek, 16 miles south of Bingara, where the genotype of *Aphrophyllum* (*A. hallense* Smith) was found. Other species of *Aphrophyllum* occur at Babbinboon.

Nearly all of the corals recorded by Etheridge (1900, pp. 5–24) from Lion Creek, Stanwell, Queensland, as well as several additional forms described by Dr. Dorothy Hill (1934) from the Riverleigh Limestone near Mundubberah, Queensland, are represented in the Babbinboon limestones: in addition, there are possibly several new species.

This strongly suggests the direct correlation of the Babbinboon and Queensland horizons. Concerning the age of the Queensland occurrences Dr. Hill states (p. 105): "The whole fauna is thus undoubtedly Upper Viséan or D in type, while *O.* (*Orionastraea*) *lonsdaleoides* and *A.* (*Aulina*) *simplex* indicate that it may be more minutely placed as homotaxial with D_2."

The corals therefore indicate that the Lower Kuttung beds of Babbinboon are Viséan in age, belonging to the Upper part of the Lower Carboniferous.

C. Summary of Fossil Plants.

Fossil plants are fairly common on certain horizons in the Werrie Basin.

The Upper Devonian Barraba Series contains only *Lepidodendron australe* McCoy: this does not appear in the overlying Carboniferous beds.

The flora of the Carboniferous rocks is as follows:

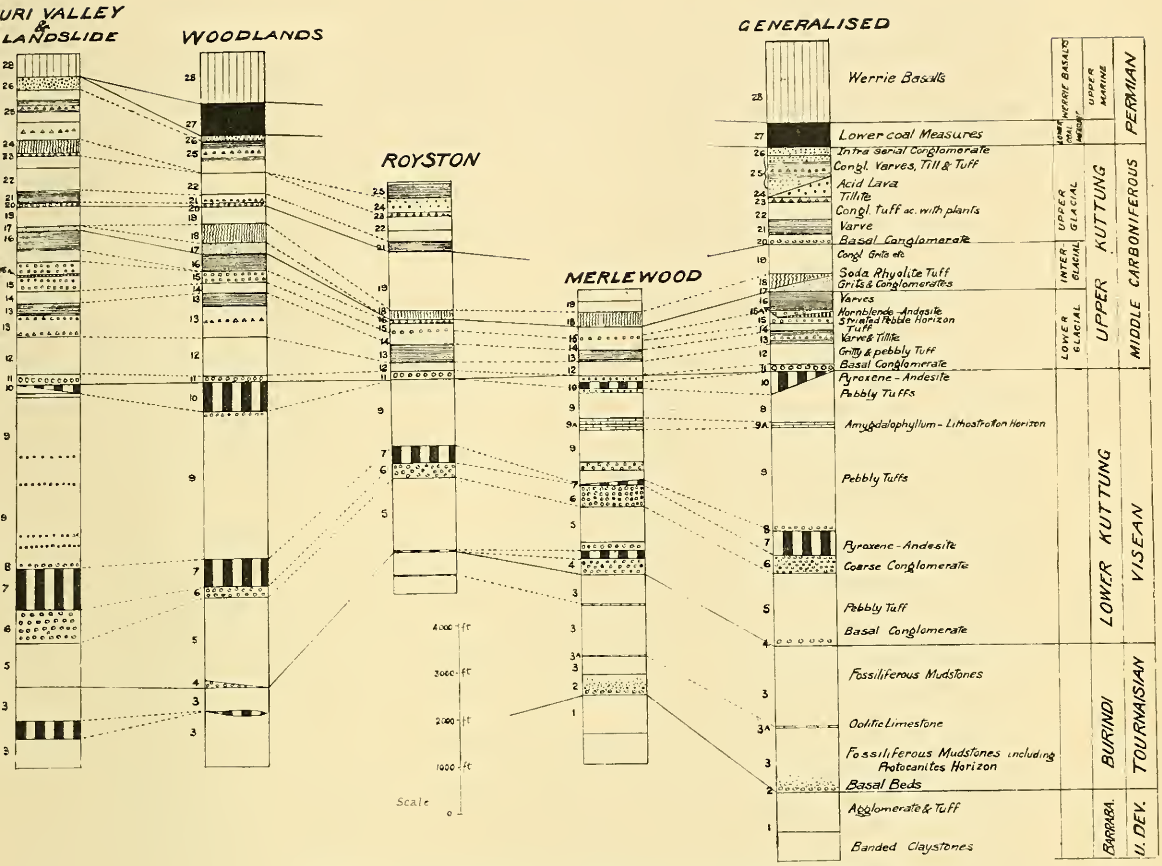
(1) *Lower Burindi Series*: *Lepidodendron Veltheimianum* Sternberg, *Stigmaria ficoides*.

(2) *Lower Kuttung Series*: *Lepidodendron Veltheimianum* Sternberg, *Stigmaria ficoides*, *Pitys* sp., undescribed plants from below the main andesite on the "Woodlands" section, including *Rhodea* (?), *Sphenopteridium* (?), *Sphenopteris* (?), etc.

(3) *Upper Kuttung Series*.

- (*a*) Lower Glacial Stage: *Rhacopteris intermedia* Feistmantel, *Aneimites ovata* McCoy, (?) *Calamites*, *Samaropsis* (?) *ovalis* Walkom 1935, *Samaropsis* cf. *barcellosa* White.
- (*b*) Interglacial Stage: *Rhacopteris*, *Cordaites*, *Archaeocalamites*, *Trigonocarpus* (?) *ovoideus* Walkom 1935.
- (*c*) Upper Glacial Stage: *Rhacopteris* spp., *Samaropsis Milleri* (Feistmantel), *Carpolithus striatus* Walkom 1935, *Cordaicarpus prolatus* Walkom 1935, *Trigonocarpus* (?) *ellipticus* Walkom 1935, *Rhacophyllum*, *Rhacopteris intermedia* Feistmantel, *R.* (?) *Roemeri* Feistmantel.

The *Lepidodendron* flora is thus confined to the Lower Carboniferous rocks, while the Middle Carboniferous Upper Kuttung Series is characterized by the *Rhacopteris* flora.



Text-fig. 3.—Correlation of Sections of the Werrie Syncline.

D. Analysis of the Carboniferous Sequence.

1. Correlation of Sections.

The correlation table (Text-fig. 3) shows the relationships of the five sections which have been described. The essential common features of each have been assimilated into the generalized section, which epitomizes the Carboniferous sequence in the Werrie Basin.

The Burindi sequence has been studied in detail only in the Merlewood area, so little can be added here. The most significant feature of this section is the finding of a rich fauna including an index Tournaisian fossil on a horizon about 700 feet above the base of the series. The only marker horizons which have been used in the field are the basal conglomerate (2)* and the oolitic limestone horizon (3*a*). The former is persistent on the western side of the Werrie syncline, but has not been looked for nor found on the eastern side. The oolite horizon has been found in widely separated parts of this area and is an important local horizon-marker, seeing that it occurs among a thick series of marine muds.

* Numbers refer to the correlation table (Text-fig. 3).

General conceptions of the origin of oolites suggest that this horizon may possibly have a wide application as an indicator.

The basal conglomerate (4) of the Lower Kuttung Series is not persistent. It is prominent in the Merlewood area, and a conglomerate already referred to north of the Woodlands section is probably also on this horizon. A pyroxene-andesite flow is associated with these conglomerates in the Merlewood area, but it has no great areal extent.

The Lower Kuttung is composed of three essential elements:

(*a*) Pyroxene-andesite flows, of which there are three—a very important horizon (7), the discontinuous Duri Peak horizon (10), and a horizon of very limited range (in 4).

(*b*) General thick masses of very coarse boulder-beds, particularly horizons (4), (6), (8), and possibly (11), but also occurring in group (9).

(*c*) Considerable thicknesses of buff to salmon-coloured pebbly and gritty felspathic tuff. These strata are represented by (5) and (9) in the section.

This combination is typical of the Lower Kuttung throughout the Werrie Basin. It is also typical of the Lower Kuttung (Basal and Volcanic stages) of the Hunter Valley, but there rapidly increasing thicknesses of lavas mask and ultimately almost completely replace these units.

A fourth element of the utmost importance is introduced with the Merlewood section, namely, the *Amygdalophyllum-Lithostrotion* marine horizon (9*a*), for this occurrence places in our hands the solution of many difficulties.

Several problems of general application arise from the analysis of the Lower Kuttung sequence. Of these, the question of the extent of the marine deposition in the Lower Kuttung, and of the Lower Carboniferous climate, and the problem of the origin and significance of the Lower Kuttung boulder beds, are all discussed in later sections of this paper.

The basal conglomerate of the Upper Kuttung Series (11) is a horizon of great interest, not only on account of the unusual size of the boulders which sometimes are found in it, but also on account of its great persistence. It has been traced for more than 50 miles in the Werrie Basin, and it is only in the Merlewood area, which is abnormal in other features, that it fails to outcrop. Moreover, it appears to be identical in lithology and horizon with the coarse basal conglomerate of the Glacial Stage described from the Hunter Valley by Osborne (1922, p. 180; 1927, p. 99; 1928, p. 575), and by Browne (1926, p. 226), and also referred to by Sussmilch and David (1931, p. 490).

During the field-work this bed has been called the Porphyry Boulder Horizon, on account of the persistent occurrence there of large rounded boulders of pink porphyry. As a matter of fact, the largest boulders are quite often not porphyry but granite; indeed, in portion 250 in the Parish of Coeypolly, boulders as large as nine feet across are visible *in situ*, and one boulder which has been disrupted by weathering appears to have been twenty feet across. It might easily be mistaken for a "pop" of granite. The outcrop is about ten yards in diameter and consists of granite blocks, some of which are about seven feet across. None of the blocks is at all rounded and it can be seen how they originally fitted together before having been disrupted along joint-planes. Another excellent exposure occurs on Werrie's Creek north of portion 176 and in portion 152 in the Parish of Werrie. Here the conglomerate is very thick and boulders more than three feet in diameter are quite numerous. The granite boulders attain the greatest dimensions, but they are not so persistent as the porphyry which seldom fails to outcrop.

Although this important conglomerate has been described as the basal bed of the Upper Kuttung, it has many features in common with the conglomerates of the Lower Kuttung. Its boulder content is essentially similar, and it is usually separated from the first obviously glacial beds in the form of varves or fluviotill by a thickness of felspathic tuff not unlike the characteristic tuffs of the Lower Kuttung. The frequent occurrence in it of silicified fragments of *Pitys* also links it with the earlier rather than with the later sediments. However, the great persistence of this formation, and the unusually large size of its boulders, justify its being regarded as the basal bed of the Upper Kuttung.

The Upper Kuttung Series admits of classification into three stages, viz., the Lower Glacial beds, the Interglacial beds and the Upper Glacial beds. The Lower Glacials have a fairly well-defined sequence. Overlying the basal conglomerate is a series of pebbly and gritty tuffs (12), which become more conglomeratic upwards. About 200 feet above the base these merge into the glacial strata (13). In the Merlewood and Royston sections only varves are developed, but in the eastern limb this glacial stage is thicker, and both varves and tillite are present. These are separated from the next glacial stage by tuffs (14). In the Woodlands and Turi Valley sections these tuffs have rather a characteristic lithology. They are well-bedded and brightly coloured in reds and greens and are probably rather acid. The next glacial horizon is so distinctive that it can be recognized immediately in any part of the area, for in all four sections this zone possesses a bed of conglomerate (15) rich in pebbles of indurated argillite which are beautifully striated and ice-scored. It is particularly thick in the Turi Valley section, but in Woodlands section it is more cemented and forms a physiographic feature.

Associated with this striated pebble horizon it is not uncommon to find a thin flow of hornblende-andesite (15*a*). It was encountered on the Turi Valley section, and has been traced for a little more than a mile on either side of that section. It is not developed in the Woodlands section, but was found in the hills about a mile and a half south-west of "Woodlands" homestead, and was traced for a mile along its strike before it disappeared. The same hornblende-andesite horizon reappears in the extreme northern part of the Upper Kuttung outcrop, but here again the flow only persists for about a mile and a half. It outcrops prominently in portions 25, 35, 74 and 73 in the Parish of Piallaway, about two miles north-east of Piallaway Station.* Here it is associated as usual with the striated pebble beds, which lead up through a glacial zone to the cliffs of conglomerate and soda-rhyolite tuff of the Interglacial Stage.

To return to the general section, the striated pebble zone is followed by varves (16) which complete the Lower Glacial Stage. On the western limb of the syncline, these varves are replaced by tillite.

The Interglacial Stage is essentially tuffaceous, without definite evidence of glacial action. *Rhacopteris*-bearing strata are always included, and normal conglomerates and grits are usually present. The most characteristic element is the soda-rhyolite tuff (18), which has a quite distinctive lithology. It is missing from the Turi Valley section, but may have been cut out by a fault, the field-evidence being rather doubtful on this point. The upper part of the stage (19) is similar in all the sections, consisting of pebbly grit, thin-bedded conglomerates and white hard grits and fine sandstones which always yield *Rhacopteris* and its

* On the geological map of the Werrie Basin (Carey, 1934) the distinctive pattern of the hornblende-andesite was accidentally omitted from this outcrop, which appears as a line of blank lenses.

associates. These beds are highly siliceous and felspathic, and probably represent redistributed tuffs.

The Upper Glacial Stage usually commences with a thin bouldery bed of conglomerate (20). The pebbles are hard and well-rounded and upwards of six inches in diameter. This horizon is characteristic of the eastern limb of the syncline but has not been found on the western limb.

The sequence within the Upper Glacial Stage is not so clear-cut as in the Lower Glacial beds.

Complexity was introduced into the sedimentary record of this phase owing to the simultaneous operation of several processes. Explosive volcanoes discharged vast showers of volcanic débris on to the surfaces of glaciers and into the glacial lakes, so that varve and till grade by insensible stages into tuffs and breccias. Acid lavas, too, pass imperceptibly into flow-breccias and tuffs. Lavas were poured over detrital dêbris, forming the matrix of volcanic conglomerates, the pebbles of which were frequently a similar lava from an earlier flow. As these lava-conglomerates are usually fairly tuffaceous, nomenclature becomes rather involved and arbitrary.

Correlation of this part of the sequence is further complicated by the fact that the western limb has thick flows of acid lava (quartz-biotite-felsite) which exceed 1,000 feet in thickness in the mountains west of Werris Creek. These are in the middle of the Upper Glacial Stage. Northwards towards Piallaway and Spring Gully, and in the central region occupied by the Quipolly dome, these lavas are represented by thinner flows separated by sediments, while in the eastern limb of the syncline they are almost entirely missing.

The upper part (25 and 26) of the Upper Glacial beds, however, is fairly constant in character. For example, the topmost conglomerate (26) is very characteristic in its occurrence throughout the area. It is not obviously glacial in its genesis and, unlike the other fluvial conglomerates in the series, its pebbles are almost entirely lavas, intraserial in origin.

A series of varves, tillites, tuffs and conglomerates always immediately underlies the top conglomerate (26). The characters of these glacial beds as they are exposed in the Woodlands and Landslide sections have already been described. The excellent exposures of this stage which have been revealed as a result of the recent constructional works at the Quipolly Dam, five miles east of Quipolly railway platform, are, to say the least of it, a glaciologist's paradise. The tillite, which is 90 feet thick, is a hard, tough rock, blue on fresh surfaces, but weathering to buff, very densely packed with chips of volcanic rocks, with a sporadic scattering of larger angular or ovoidal lava-boulders measuring up to two feet in diameter. They are frequently arranged with their longer axes upright, often dumped big end up. The rock breaks across matrix and boulders alike, and the tough matrix is more resistant to weathering than the enclosed boulders. Irregular layers and lenses of varves, often much brecciated, are scattered through the tillite; they may be masses which were torn off, incorporated in the ice-sheet, and deposited when it melted away.

So predominantly is the material which has contributed to the formation of this tillite of volcanic origin, that the first exposures were regarded as volcanic tuffs and breccias. The volcanic rocks present include such types as hornblende-andesite, pyroxene-andesite, dellenite, toscanite, felsite, albite-rhyolite, biotite-porphyrite, ophitic basalt and occasional indurated sedimentary rocks, apparently derived from a Devonian terrain forming the basement to the lava-field undergoing glaciation during this part of Kuttung time.

Above and below the tillite are varves, those beneath showing fine contortions, and those above finely-paired annual laminations. McCarthy's Creek, on the eastern side of Quipolly Dome, provides an excellent exposure of the varve-horizon immediately beneath the Quipolly Dam tillite, where the plastic material of the soft rocks has been crumpled in an extraordinary fashion.

A short distance below the varves at Quipolly Dam is an important plant-horizon which has been fruitful in its yield of fossil seeds. Several specimens of *Samaropsis Milleri* (Walkom, 1935) have been obtained from this locality as well as *Carpolithus striatus*. The same horizon has been productive of seeds of varying species at many localities in the Werrie Syncline.

2. SEQUENCE OF SEDIMENTATION.

Relation of Carboniferous to Devonian.

There has been considerable doubt concerning the identification of the basal portion of the Carboniferous System in New South Wales. Benson (1921) discussed the question at some length, and came to the conclusion that the Burindi fauna was of Viséan age, and that, in view of the conformability of the Barraba and Burindi Series, there must be an important diastem representing the Tournaisian epoch at the junction of these two formations, or the true base of the Carboniferous must be at some unrecognizable horizon in the Barraba Series. Benson favoured the latter interpretation. Following up this statement, the present author held that if part of the Barraba be included in the Carboniferous, the base of that system should be extended down to the base of the Baldwin agglomerates, since the Baldwin-Barraba Series were a natural unit in their flora, sequence of facies, and genesis—a unit which has its base in the Baldwin agglomerates. The whole question hinged round Benson's determination of the Burindi fauna as a Viséan assemblage, a verdict which had never been questioned.

However, as the present writer's examination of the district progressed, it soon became evident that there was much confusion concerning the precise localities from which the Babbinboon faunas had been collected, and clarity was only attained after a personal discussion with Professor Benson, and with Mrs. Scott, whose collections were included in Benson's descriptions. The writer also consulted Mr. Mackay, of "Allanbank", who as host had conducted Benson through the Babbinboon district, and Messrs. A. H. and H. J. Perfrement, the owners of the properties concerned, who were able to say precisely what localities were visited.

The specimens of *Amygdalophyllum* described by Dun and Benson (1920) were part of a collection made by Mrs. Scott from the Merlewood Lower Kuttung limestone, but which also included some fossils from the Burindi Series near Royston. Not suspecting any marine strata in the district other than the Burindi Series, Benson recorded all these specimens as Burindi with the general locality of "south-east of Babbinboon", although the Merlewood part of this collection is in the extreme north-east of that Parish (portion 60). The issue is further complicated by the fact that Benson made a rapid sulky reconnaissance up the valley past Royston and Merlewood to near Somerton, as the guest of Mr. Mackay, collecting on the way. The route traverses only Burindi strata and Benson recorded having obtained *Amygdalophyllum* beside the road, his specimen being figured with the description. Dr. Stanley Smith pointed out later, however, that this figured specimen was not *Amygdalophyllum* at all, but *Zaphrentis sumphuens* (Benson and Smith, 1923). The result is that there is now no authentic record of *Amygdalophyllum* from the Burindi Series of New South Wales. It should also be pointed out that the "low hill capped with a horizontal layer of fine-grained limestone" described by Dun and Benson (*loc. cit.*, p. 289) as occurring "adjacent to portion 14 of the Parish" of Babbinboon is really in the Parish of Somerton adjacent to Mr. Watt's homestead.

A second pertinent discovery was the recent finding by the writer of cephalopods in the lower part of the Burindi Series in the same section, which have been identified by Dr. Ida Brown as Tournaisian types.

These discoveries have filled in the gaps in the stratigraphical record so that now there is no important break in the sedimentary sequence between the Middle Devonian and the Upper Carboniferous, and the base of the Carboniferous is accurately fixed at the base of the Burindi Series.

In the field-exposures no suggestion of structural unconformity has been found between the Barraba and Burindi Series. In Swain's Gully in the Parish of Babbinboon, the conformable contact of the two formations is exposed, and for several miles there is a continuity of outcrop of the bouldery agglomerate of the igneous zone at the top of the Barraba Series and the basal conglomerate of the Burindi Series.

Lateral Variation and Overlap in the Carboniferous Sequence.

The Burindi and Kuttung Series are conformable throughout. Although in the Lower Hunter Valley the Glacial Stage (= Upper Kuttung Series) has been found to overlap on to a granitic basement, no section has been found in the Werrie Basin where any portion has been cut out by overlap. The question arises as to the position of Osborne's Basal Stage of the Kuttung Series (the Wallarobba Conglomerates) in the Werrie Syncline section, and whether there is a diastem in the latter sequence corresponding to them.

There is no evidence to suggest that this is so. The Wallarobba Conglomerates are here interpreted as a local specially heavy development of the coarse conglomerates which are characteristic of the Lower Kuttung. Several hundred feet of the Lower Kuttung in the Werrie Basin are made up of such beds, which answer closely to the description of the size, shape and lithology of the boulders present in them at Wallarobba (see Sussmilch and David, 1919, p. 262). The facies is well within the limits of a lateral variant of a boulder-deposit of the Wallarobba type in a distance of nearly two hundred miles, even though the direction be essentially concordant with the palaeogeographical facies lines.

The origin of the conglomerates is discussed at some length in the climatic section which follows, and it is there suggested that they represent fluvio-glacial material deposited a considerable distance from the glacial front, which was well to the south-south-west. Under these circumstances it is natural to expect the heaviest development of conglomerates in the most southerly exposures, as at Wallarobba, and that two hundred miles further to the north-west there would be finer strata intercalated among the boulder beds.

A diastem of the first order may perhaps occur at the base of the Upper Kuttung. The extraordinarily large size of some of the boulders, and the remarkable persistence of the basal conglomerates have already been mentioned, and it is likely that such a feature may cover an important time-break.

The only other place within the Kuttung sequence where there is any reason to suspect a hiatus is at the base of the Upper Glacial Stage.

Lateral variation in the Carboniferous sediments has arisen from the distribution of the igneous rocks, the palaeogeography of the ice-sheets, the regional supply of materials, and differential subsidence causing thickness variation.

The first of these factors is the most obvious. In the Lower Hunter Valley there are great suites of effusives giving rise to a Volcanic Stage which is represented mainly by tuffs in the Werrie Syncline. The thick acid lavas of the western side of the Werrie Syncline are practically missing from the eastern side. The Duri Peak flow is more than 1,000 feet thick, but two miles along the strike it has cut out altogether, and so on; the examples could be multiplied.

Glacial variation is not so marked. A tillite in some of the sections is represented by varve in another and by fluvio-glacial conglomerate in a third. The glacial conglomerates are more variable than are the varves; but these variations are local, not regional. By making a large series of sections, it would be possible to delimit the boundaries of the glacial lakes in which the varves were deposited, but this has not been attempted.

Within the Werrie Basin the conglomerates seem to be coarser and thicker towards the west, but the total thicknesses of the stages to be less. This suggests that the source of the boulders lay in that direction, that the axis of geosynclinal subsidence was somewhat to the east of the axis of the present Werrie syncline, and that there was a progressive basinward thickening consistent with the subsidence. The lavas, too, thicken westwards or south-westwards and were probably extruded from that side. It is of interest to mention here that the Lower Coal Measures, which overlie the Carboniferous strata in the Werrie Basin, thicken and become coarser north-eastwards instead of south-westwards, and in the north-north-west they are overlapped against the Kuttung rocks. So it is apparent that there was a change in both the source of supply of material and in the axis of subsidence in the intervening period.

Relation of Carboniferous to Kamilaroi.

At the top of the Kuttung Series in the Werrie Basin there is an important non-sequence without angular divergence, which corresponds to the overlap of the Lower Marine Series, and in the north-west part of the region, of the Lower Coal Measures as well. This break may correspond in part to Uralian time (see Sussmilch, 1935, pp. 102–104), and in any case extends well into the Lower Permian.

Extent of Marine Sedimentation in the Lower Kuttung.

Prior to the discovery of the *Lithostrotion-Amygdalophyllum* beds among the Lower Kuttung strata of the Werrie Basin, these latter were accepted without question as a terrestrial series. Following on the discovery of the marine fossils in the Babbinboon district, Sussmilch suggested that the upper portions of the Carboniferous marine beds in the Gloucester district, which he had previously referred to as the Burindi Series, might really be homotaxial with the Lower Kuttung (Sussmilch, 1935, p. 100). The present writer had previously made a similar suggestion with regard to the adjacent Myall Lakes area (Carey, 1934). Furthermore, the correlation of the *Amygdalophyllum* limestone of the Werrie Basin with the Lion Creek limestone of Queensland, makes it clear that some of the Queensland time-equivalents of the Lower Kuttung are marine.

Thus, in personal conversations with the writer, the question has been rather pointedly raised: Are the Lower Kuttung sediments of marine origin? It is true that *Lepidodendron Veltheimianum* and *Stigmaria ficoides*, etc., have been obtained from them; but these same fossils have been collected from the Burindi Series, where they occur cheek by jowl with a rich marine fauna. So may they not represent drift material into an estuarine sea?

This problem may be approached along more than one avenue. An analysis of the internal evidence of the marine strata of the Babbinboon district is interesting in this connexion.

The marine beds outcrop for about three miles, and in this distance there is a progressive facies change indicative of increasing depth northwards from a strand-line south-east of "Merlewood" homestead (see Plate xviii). On the Merlewood section line (the north boundary of portion 61 in the Parish of Babbinboon) the horizon is represented by 270 feet of oolitic grits and conglomerates. Oolites in general are characteristic of a very shallow-water facies and often represent beach-deposits, and an oolitic conglomerate of this type is clearly a near-strand bed. The lithology of the pebbles, consisting as they do of well-worn ellipsoids, well graded in size, shape and mechanical resistance, is obviously the result of prolonged winnowing and attrition by the waves in the shingle zone. No marine life throve in this environment. In contrast to the prolific collecting-ground northwards along the strike, several hours' search up and down the naked outcrops of this zone yielded only a single battered crinoid ossicle, which was probably transported thither by the waves. Northwards from this inshore-facies, across the north boundary of portion 3 into the western part of portion 10, the oolite zone widens, and as it does so it fingers out, becoming interdigitated with normal shallow-water marine conglomerate. This gradually increases at the expense of the oolite, and in a short space the latter has wedged out entirely. Towards the north-western sector of portion 10 the conglomerate attains its maximum development, rising to form an elevated cuesta. This portion of the deposit is best interpreted as an off-shore shingle-like conglomerate deposited in a current-zone.

The conglomerate continues through portion 26 (locally known as the "Dight 40-Acre") and through the western leg of portion 14, but it is dwindling rapidly meanwhile, and by the time the windmill on the bank of Swain's Gully in that portion is reached, there are only a few feet of gravel left to represent the bed, which could easily be passed over even by someone looking for that conglomerate horizon. For, although this environment is beyond the off-shore conglomerate zone, it has not yet reached the zone of abundant marine life. However, a short distance north of the windmill, at a small shoulder which has been called "Hill 60" after the number of the portion in which it stands, the reef-coral facies appears with surprising suddenness, with a prolific development of *Lithostrotion*, with *Amygdalophyllum*, *Syringopora* and other forms as accessories. The corals are most prolific at the southern (near-shore) end and northwards the bed rapidly tapers off, until in a couple of hundred yards it has dwindled to isolated "stringers" of limestone, which are mostly barren. This passes into a marly zone packed with thin-shelled *Mourlonia*, clearly representing a slowly deepening habitat. Nearby is a spot which has yielded a few brachiopods (*Spirifer* cf. *mosquensis*). Beyond are mudstones with occasional thin lenses of barren limestone.

The Merlewood fossiliferous horizon, then, provides a fine study in a progressive facies change in a single thin bed along three miles of strike, from an inshore shingle through the current-zone, to the coral-reef, and into the deeper waters beyond. It leaves little doubt which way the land lay. The shore was to the south—between the Merlewood and Royston sections. The latter contains no marine beds on this horizon; it is the normal section of the Lower Kuttung as it is usually developed in the Werrie Basin—a terrestrial series.

A second approach to the question of the extent of marine deposition in the Lower Kuttung is by way of the conglomerates. It does not seem feasible that the thick boulder beds recurrent through this series were transported and distributed by the sea. They are not marginal conglomerates which change their facies in a few miles of strike. They persist for long distances, and continue around large structures, which thus introduce the second dimension of areal distribution into the problem. Their field-relations leave no doubt that they are sheet-deposits. It is admitted that sheet boulder beds of wide extent may be deposited by a steadily retreating sea. But such deposits are usually obliterated during the subsequent marine advance. (For a discussion of the environmental conditions of such conglomerates see Twenhofel, 1936, pp. 681, 682.) The Lower Kuttung examples have not the characters of marine conglomerates of this type.

Terrestrial waters are able to attain flushing volumes and velocities and with impulsive transporting power greatly in excess of the capabilities of the sea which, except along the strand line, depends on smaller forces acting for longer times to transport greater total quantities but in smaller individual masses. Although surprisingly powerful sea-floor velocities have been recorded by some investigators (Twenhofel, *loc. cit.*, pp. 686–7), marine sets and currents are never strong enough to distribute large boulder beds over wide areas.

It is interesting to compare the pebbles in the proven marine conglomerate of the same age with the normal Lower Kuttung conglomerates. In Babbinboon, as we have seen, a littoral shingle laterally separates the oolite facies from the reef-coral facies. It occurs in an environment where the transporting power of the currents might be expected to be a maximum. The pebbles seldom exceed three inches in major diameter and have usually two nearly equal minor diameters, a form produced by and amenable to wave and current transportation. The finding of these foreign pebbles belonging to marine strata interbedded among very coarse boulder beds radically different in source, size and lithology, suggests immediately that the coarse boulders reached their destination by a terrestrial route and that the marine gravel was transported thither by a different way and by a different agency.

The fossil content of the Lower Kuttung, too, throws some light on the problem. With the exception of the *Amygdalophyllum-Lithostrotion* horizon itself, no marine fossils have been found anywhere in the series. Plant horizons are fairly numerous. Some of these could be regarded as drift material buried among marine sediment. But others, like the *Rhodea* (?) horizon in the Woodlands section, where the shale is packed with thin-pinnuled ferns, are almost certainly freshwater beds.

Moreover, the pyroxene-andesite flows show no evidence, such as pillow structure, or sub-marine zeolitization, of having been extruded on the sea-floor.

To sum up, there is much to suggest that the Lower Kuttung of the Werrie Basin is essentially a terrestrial series, with but little contrary evidence. However, the fact that a temporary invasion of the sea took place in the north-west corner of the Werrie Basin with no disturbance of the sedimentary record in adjacent areas, shows that the terrestrial strata were deposited close to sea-level.

3. SEQUENCE OF CLIMATES.

Interpretation and Significance of Lower Kuttung Conglomerates.

One of the problems of the Lower Kuttung is that of the origin and significance of the great thickness of coarse conglomerates which are characteristic of this Series.

It has already been pointed out that they are widespread sheet deposits of terrestrial origin, which recur again and again in the sequence. They are not glacial conglomerates in the ordinary sense, for the boulders are well-rounded and rudely graded and bedded, and signs of glacial markings are extremely rare. In the wide region over which these beds have been examined, the only record of Lower Kuttung glaciation is contained in varve-shales and fluvio-glacial conglomerates in the Gosforth district, Lower Hunter Valley (Browne, 1926).

In considering the origin of these conglomerates it is necessary to conceive of both a source for the boulders and an aqueous agent which could repeatedly distribute such large boulders uniformly over so wide a field.

The most probable explanation seems to be that they represent sheet-apron deposits transported well out beyond a piedmont glacial front. Their wide distribution and general characters and lithology and the usual lack of any sign of glacial faceting or striation on the boulders, indicate that they were laid down beyond the zone of eskers and kames, even beyond the terrain of ordinary fluvio-glacial deposits; the contribution of the glaciers was to provide large quantities of bouldery material and the large impulsive volumes of water capable of completing the ablation to the ultimate site of deposition.

The highlands which supplied the glaciers probably lay to the south-west. The higher grade glacial deposits would be entirely removed from this region by the subsequent erosion during the rest of the Carboniferous and Permian periods. For at Gosforth and Pokolbin Upper Kuttung strata rest unconformably on a stripped granitic terrain, and further west Upper Marine and Upper Coal Measure strata are lying directly on an eroded basement of Middle Palaeozoic rocks. Thus the record of this earlier glaciation is preserved only in boulder beds which were deposited a long way from the scene, beds which were least fitted to tell the tale.

Sir Edgeworth David has compared this schotter gravel apron with the present fluvio-glacial flood-plains of Alaska (1932, p. 57). Mr. J. N. Montgomery, who spent a number of years in Persia (Iran) with the Anglo-Persian Oil Company, has suggested* that another possible analogue to the Lower Kuttung conglomerates is to be found in the boulder-beds of the Upper Bakhtiari Series in south-west Persia. Nobody has ever suggested that these thick, coarse conglomerates are fluvio-glacial, nor have any ice-scratched boulders been recorded from them. They are probably Pleistocene in age, and may represent the ultimate terrestrial outwash from a big glacial front in the Zagros Mountains and the Central Persian Plateau, which would almost certainly be glaciated at this time in view of the fact that the Lebanon Mountains adjacent to the Mediterranean were heavily glaciated, and that the ice reached down to 4,500 feet in latitude 26 degrees in Bengal, and to 2,000 or 3,000 feet in the Western Himalayas (Coleman, 1908, p. 348). The extent and thickness of the Bakhtiari conglomerates and their general characters seem to be analogous to those of the Lower Kuttung conglomerates.

The significance of the interpretation of the Lower Kuttung boulder beds is that the Carboniferous refrigeration of Australia first manifested itself in Viséan time, for the faunas of the Werrie Basin have made it clear that the Burindi Series there is essentially Tournaisian, and the Lower Kuttung is Viséan. It has already been pointed out that the Lower Kuttung sedimentation took place close to sea-level. The Viséan climates were not sufficiently cold to bring the glaciers down to this sedimentary plain. Herein we have a qualitative climatic index for this portion of the Carboniferous Period.

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* Personal discussion with the writer.

Significance of Lithostrotion *Horizon.*

The assumption of glacial connexion for the Lower Kuttung conglomerates immediately raises the question of the climatic implication of the *Lithostrotion-Amygdalophyllum* bed, which is in sufficiently close association with the conglomerates to provoke comment.

Under the doctrine of the continuity of geological processes it has been customary to assume that the presence of reef-building corals is indicative of warm (essentially tropical) seas. In view of the repeated demonstration in many parts of the geological record of the remarkable adaptability of organic life to even wide environmental changes, this assumption is not wholly justified. Palaeozoic reef-corals may have flourished in seas considerably colder than is the rule to-day. Nevertheless, it is probably fairly safe to assume that the occurrence of a reef-coral zone in a sub-glacial sequence indicates a temporary warming of the seas during an interglacial phase.

If this interpretation is correct reef-corals would only be found in the restricted zone of the temporary amelioration of climate.

Speaking of the Carboniferous faunas of Queensland, Whitehouse (1930) wrote: "At no locality has more than one limestone bed yielded reef-corals. It seems, therefore, that conditions for reef-corals in Eastern Australia during the Carboniferous were limited to a very short period." The coral horizon of Whitehouse is the Lion Creek *Amygdalophyllum-Lithostrotion* bed which is homotaxial with the similar horizon in the Werrie Basin now under discussion.

It would seem, then, that the horizon represents a lull between the sub-glacial conditions of the Lower Kuttung and the more intense refrigeration of the Upper Kuttung.

Climatic Interpretation of the Upper Kuttung.

Little has been done as yet towards an analysis of the glacial record preserved in the Upper Kuttung sediments, in order to reconstruct the sequence of glacial and interglacial epochs. A detailed study of this question would present interesting problems in the disentangling of the glacial from the pyroclastic suites.

It is clear from the outset that two main cold epochs are represented by the Upper and Lower Glacial Stages, and that these were separated from each other by the epoch of the Interglacial Stage, the conglomerates and grits of which are distinctly free from ice-action.

Studies of the details of the glacial rocks frequently yield clear accounts of the climatic changes which have taken place during their deposition. For example, at the Gap west of Werris Creek the gradual advance of the ice-sheet to its maximum followed by its steady waning, is faithfully recorded through seventeen hundred feet of strata, which overlie the lavas there. The lavas are followed by volcanic conglomerates composed of felsitic boulders in a matrix of fragments of the same material. The finer gritty phases are rather susceptible to chemical destruction and show typical spheroidal weathering to a rotten, green rubble. But the initial disintegration which produced these rocks in Kuttung times was dominantly mechanical rather than chemical, and savours distinctly of freezing and thawing action; this first suspicion of glacial conditions is immediately confirmed by the appearance of varves. The varves are 250 feet in thickness and towards the top there is a sudden disposition to contortions, yielding some beautiful specimens, due to the impress of overriding glaciers of an advancing ice-sheet. The varves in turn pass upwards into 300 feet of glacial grits and tillite, which represent the culmination of the glacial advance. The tillite passes by gradual transition into another 830 feet of varves which are overlain by aqueo-glacial grits denoting a considerable retreat of the ice-sheet. The final bed of the suite is 260 feet of fluvio-glacial conglomerate, deposited a considerable distance from the ice-front. The pebbles are ill-sorted with occasional large erratics, but they are usually water-worn and no longer retain identifiable striations.

When these methods are applied to the systematic sections, it will be seen that beds (12), (13) and (14) in the Lower Glacial Stage represent a complete glacial cycle of advance, culmination and retreat. This is most clearly shown in the Woodlands section. Beds (15) and (16) record the second advance, which was not quite so severe as the first. The Interglacial Stage follows, and here the conglomerates and grits which accompany the tuffs all have the normal lithology of a water-transported sediment. This is a long interglacial break. In the Upper Glacial Stage there are two short glacial epochs, represented by beds (21) and (23), which are separated by an interglacial group of sediments, and a culminating prolonged advance (25) recorded by the spectacular glacial deposits of Quipolly Dam, McCarthy's Creek, and the Gap near Werris Creek, the last of which has just been described.

To recapitulate, the internal evidence of the Upper Kuttung of the Werrie Basin indicates two successive glacial advances followed by an important inter-glacial break, then two short glacial advances followed by a final prolonged refrigeration, which completed the Kuttung cycle (see Text-fig. 4).

Climatic Evidence of the Tuffs.

In the Werrie Basin Upper Kuttung can usually be distinguished immediately from Lower Kuttung tuff on its lithology alone,* and there is at least a suspicion that climatic conditions may have contributed to this as much as, or more than, chemical or petrological differences.

The tuffs interbedded with the glacial stages are often as hard as the lavas from which they are derived. Colours are bright in reds, greens, blues, greys and browns, much like lithoidal lava groundmasses. This material often shows evidence of magmatic weathering prior to ejection (with the generation of haematite, albite, chlorite, etc.), but no pre-depositional subaërial weathering, or weathering by connate waters. An excellent example is the Gap volcanic conglomerate already quoted (p. 365). Such tuffs are not found in the Lower Kuttung where depositional weathering is the rule.

In the Interglacial Stage there is a considerable quantity of pebbly water-redistributed tuff, the manner of accumulation of which must have been very similar to that of the pebbly tuffs of the Lower Kuttung. The grainsize, texture, bedding, manner of sorting, and sedimentary admixture, are all very similar in both groups, and both are acid and felspathic. But those in the Lower Kuttung are invariably warm buff, brown, or salmon-pink in colour, whereas those in the Interglacial Stage are white. The former are soft and friable from pre-depositional weathering, the latter are fresh and hard. The differences are probably largely climatic.

The most probable interpretation of these observations is that the tuffs of the Lower and Upper Kuttung express an increasing grade of climatic severity.

This is a line of investigation which must not be pressed too far on the data available at present, but which might well be pursued further by later workers.

* This may or may not also be applicable to the Lower Hunter Valley, because there is greater complexity in the volcanic sequence in that region. (Vide p. 369.)

The Plants as Climatic Indicators.

As yet little has been done in the interpretation of the climatic significance of the Carboniferous floras, although ultimately they may provide one of our most valuable keys.

The silica-petrifactions of *Clepsydropsis*, and of *Pitys* with well-developed annual rings, in the Lower Kuttung may be interpreted climatically after detailed palaeobotanical work.

Leaf impressions of *Cordaites*—a gymnosperm tree—occur in the Interglacial Stage in the Werrie Basin.

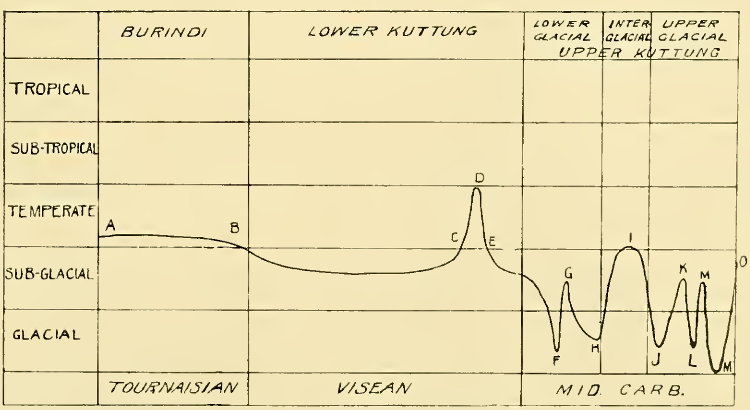
So far as the writer's observations go, the *Rhacopteris* flora is associated with the warmer theses (see Huntington, 1907, p. 362) between the periods of glacial advance. Thus *Rhacopteris* is always well developed in the finer beds of the Interglacial Stage, deposited during the most important interglacial epoch of the whole glacial strophe; and, where *Rhacopteris* is present in the glacial stages, the beds which actually carry the flora usually have a lithology similar to the plant-beds of the Interglacial Stage, often with pebbly and gritty bands with a non-glacial appearance, although they are interbedded with varves and tillite. Browne has recorded *Rhacopteris* from varves in the Gosforth section (1926), but in the writer's experience such occurrences are very rare.

Much may result from a detailed investigation of the Pteridosperm group, and the assigning of vegetative organs to the many fossil seeds which have been found in the Upper Kuttung of the Werrie Basin, and an ultimate interpretation of the life-cycle of those plants and the conditions governing the ripening of their fruits. Petrifactions of this material are highly desirable.

Reconstruction of the Climatic Sequence.

The problem of the Carboniferous climate has now been approached along various independent lines of inquiry. The results of these investigations have been co-ordinated and expressed qualitatively as a graph of climate against time (Text-fig. 4).

In this diagram the section between A and B expresses the environment of the Burindi Series. The preceding Devonian Period had been warm and arid, as indicated by the extensive coral-reefs of the Mid-Devonian, and the succeeding red beds of the Lower Drummond and Dotswood formations of Queensland and else-



Text-fig. 4.—Climatic Sequence in the Carboniferous Rocks of the Werrie Basin.

where (Reid, 1930, p. 221; David, 1932, p. 48). The Burindi sediments contain no suspicion of ice-action and the fauna is one which is typical of temperate rather than tropical seas. Although the depth oscillated between a shallow oolitic facies and a deeper mudstone facies beyond the brachiopod zone, there is no authentic record of reef-coral. In the highest fossiliferous horizon of the Burindi Series in the Woodlands section, the forms are conspicuously dwarfed, a fact which may reflect the incipient refrigeration of the coming glacial epoch (David, 1932, p. 59).

The sub-glacial condition indicated between B and C is based on the interpretation of the Lower Kuttung conglomerates as outlined in the foregoing remarks. This part of the curve should probably be more oscillatory than is indicated. It may eventually be possible, by correlating the successive boulder horizons with advances and retreats of the distant ice-sheet, to make the curve more complete. It may also be possible to approach the problem by a careful study of the facies of the faunas of the Upper Rockhampton Series in Queensland, for there a complete marine faunal record is available for the section between B and C.

The warm interglacial epoch marked by the curve CDE is recorded by the restricted reef-coral zone of the *Amygdalophyllum-Lithostrotion* horizon. The height of the apex of the curve at this point is rather arbitrary. It almost certainly extended well into the temperate zone, and perhaps even into the subtropical.

The succession of glacial advances and retreats between E and O is exactly in accord with the internal evidence of the glacial strata as outlined in the preceding remarks. The curve GHI is steeper on the right hand side because the retreat of the ice-sheet was apparently very rapid and left little to represent it, whereas in the glacial advance recorded by MNO both advance and retreat are outlined through a thick series of strata, so the curve is more symmetrical. The most intense glaciations occurred at F and N, and the most prolonged interglacial epoch at I in the Interglacial Stage.

Each of the glacial advances contains considerable thicknesses of varves, which should lend themselves to analysis according to the principles of the school founded by Baron De Geer.

The graph which has been constructed is meant to be regarded as a qualitative first approximation, and its shortcomings must not be overlooked. For example, there are fundamental principles of stratigraphy which cannot be set aside. Whole glacial cycles may be obliterated by subsequent advances, leaving scarcely a recognizable diastem, and Barrell's law, that the rate of sedimentation is a direct function of the rate of subsidence, is partly applicable if it is stated in the more generalized form, that sediments will not continue to accumulate in an environment where rate of removal equals or exceeds rate of supply.

However, in spite of these drawbacks, it is hoped that the graph may be of value as a first attempt to depict the Carboniferous climatic sequence, and as a foundation for further research.

It is of interest to compare this curve, which has been derived solely by plotting the internal evidence of the sediments, with general conceptions of the behaviour of climatic cycles (see figure in Huntington, 1907, p. 362). If the Carboniferous climatic curve be extended back to the warm conditions of the Devonian red beds and reef-corals, and forward through the waning glacial conditions of the Kamilaroi (Sussmilch and David, 1931, table facing p. 514), it will be seen that the Devonian and Lower Carboniferous correspond to one of Huntington's interstrophes. The glacial strophe reaches its acme in the Upper

Glacial beds, diminishes again through the Lower Kamilaroi, and is completed with the Bolwarra Conglomerate. An important thesial epoch equivalent to the Interglacial Stage, but on the other side of the acme, is represented by the Lower Coal Measures. To judge by the Upper Permian insect fauna (David, 1932, p. 68), it was well into the Triassic before the climate fully recovered from the effects of this great ice-age.

4. Sequence of Vulcanism.

The development of volcanic products in the Kuttung Series of the Hunter Valley has received a good deal of attention, particularly in the writings of Osborne (1922, 1925, 1926, 1929), Browne (1926, 1929), and Sussmilch (1928, 1935). So impressive are the lavas there that Osborne designated the upper part of the Lower Kuttung the Volcanic Stage, and successfully used indicator lavas as markers (the Martin's Creek andesite and the Paterson toscanite, etc.) for some of his subdivisions of the Kuttung sequence.

In the Werrie Basin there is also an extensive development of lavas, but, apart from the pyroxene-andesites, which seem to have maintained a remarkable persistence of horizon throughout, the incidence of the various lava-types in the stratigraphical column is not the same as in the Hunter Valley.

Distribution in Time.

There are no proven lavas in the Burindi Series of the Werrie Basin, and tuffs play a very minor part.

The flows of the Lower Kuttung are almost exclusively pyroxene-andesites, which attain great thickness. They are developed on two principal horizons—the main horizon nearly 2,000 feet above the base of the Lower Kuttung and about 3,000 feet from the top of that series, and the discontinuous horizon of Duri Peak at the top of the Lower Kuttung. In the Merlewood area this horizon is underlain by a locally important horizon of biotite-felsite, and followed by another thin felsite. These are the only extrusive representatives of the thick suite of acid and intermediate lavas of the Volcanic Stage of the Hunter Valley.

The Lower Glacial beds are frequently without lavas, and, so far as the Werrie Basin is concerned, these are confined to hornblende-andesites, the flows of which are developed in several places in association with the striated pebble horizon (15).

On the divide between Jacob and Joseph Creek and Coeypolly Creek there is a thin local flow of hornblende-andesite at the base of the Upper Kuttung, which may be on the horizon of the hornblende-andesite of the Mid-Hunter Valley.

The Interglacial Stage, too, is usually free from lavas, but the soda-rhyolite tuffs (18) which are characteristic of this stage grade locally into a tuffaceous flow, as for example in portion 25 in the Parish of Piallaway.

Apart from the hornblende-andesite at the Gap west of Werris Creek, the Upper Glacial beds have only acid lavas—mainly felsitic types with large phenocrysts of quartz and biotite. These occur about in the middle of the Upper Glacial Stage, where they attain great thicknesses on a horizon which appears to be slightly higher than that of the Paterson toscanite of Osborne. Owing to the complexity of the structure, caution is necessary in discussing the horizon of the Gap hornblende-andesite, but it is probably to be placed between horizons (24) and (25) of the generalized table (Text-fig. 3).

On a review of the sequence of lavas in the Werrie Basin it is seen that the Lower Kuttung is characterized by thick pyroxene-andesites, the lower glacials by thin hornblende-andesites, and the upper glacials by thick acid lavas with some hornblende-andesite. So far as this restricted region is concerned, the order of extrusion is simply one of increasing acidity.

Explosive activity was practically continuous throughout Kuttung time. The tuffs are uniformly acid, but the acidity and alkalinity seem, so far as one can judge by their lithology, more marked in the Upper than in the Lower Kuttung.

Distribution in Area.

The distribution of the pyroxene-andesites in the Werrie Basin is shown in the map already published (Carey, 1934). There are three horizons—a restricted zone of sills in the Burindi Series, the main flow horizon in the Lower Kuttung Series and the Duri Peak horizon at the top of the Lower Kuttung Series.

The Duri Peak horizon is discontinuous in outcrop and its thickness is subject to rapid variation. The main flow, on the other hand, is very persistent and is usually several hundred feet thick.

From the point where it is cut off by the thrust near Piallaway the main pyroxene-andesite is traceable in a northerly direction for six miles before it thins out. It reappears on the eastern limb of the syncline, and southwards maintains an unbroken outcrop and physiographic prominence for thirty miles until the limit of the map is reached. It attains its greatest known development near Gaspard Mountain, where it passes out of the mapped area, trending towards the Liverpool Range.

On comparing the eastern and western limbs it is seen that on both sides the andesites thin out towards the north, but that they extend further up the west flank than the east. A study of the map suggests that the greatest thickness is to be expected in a west-south-west direction. Unfortunately the outcrop of the Lower Kuttung in this direction is cut off by the Mooki Thrust system, and by the regional plunge westwards off the New England geanticline.

The widely scattered thin flows of hornblende-andesite contribute little information, but the extensive acid lavas of the Upper Glacial beds confirm the suggestion given by the pyroxene-andesites. These lavas attain their maximum development in their most western exposure. In the Quirindi dome west of Werris Creek the acid flows attain a thickness of considerably more than a thousand feet. Four miles east from here in the Quipolly dome these thick extrusives have been reduced to thin flows separated by sediments; the eastward thinning is apparent on the two sides of the dome. A similar state of affairs is found in the Castle Mountain Dome. Two miles further east, where the general horizon reappears in the eastern limb, only rare thin stringers are left to represent them.

Thus the distribution of the lavas, both acid and andesitic, points to the conclusion that they were extruded from the west, rather than from the east.

Extrusive Character of the Andesites.

In 1920 Dr. W. N. Benson, discussing the geology of the Currabubula district, reported the occurrence of three horizons of more or less glassy pyroxene-andesite. These he considers to be intrusive sills, although he points out that "no indubitable evidence of the intrusive nature of the main zone of pyroxene-andesite has yet been found, and its classification rests chiefly on the lithological similarity with the rock of the eastern zone" where definite evidence of intrusion is found.

This determination of the Currabubula andesites as sills, although tentative, has led to many doubts in later literature. For example, Osborne (1922, p. 164), referring to the pyroxene-andesites of the Paterson district, wrote: "Thus the only horizons about which any doubt remains are the more basic and those which elsewhere in the State appear to be sometimes definitely intrusive and which, in the area under consideration, are not accompanied by tuffs of similar composition." In a subsequent paper (1925, p. 113), Osborne describes the Clarencetown andesites as flows.

Later, Professor Browne (1929, p. xxviii), in his review of the Palaeozoic igneous activity of New South Wales, again refers to this matter: "We do not yet know, for example, and only detailed field-work can tell us, why it is that in the southern areas the andesitic magma made its way to the surface, whereas in the more northern parts as at Currabubula, sill-intrusions and dykes appear to be the rule, though further to the north-west andesite flows are interbedded with the Kuttung conglomerates."

Since these papers appeared the present author has examined the andesites throughout the Werrie Basin, of which the Currabubula district forms a part, and has found abundant evidence that, although those pyroxene-andesites which occur within the Burindi Series are undeniably intrusive, as Benson has shown (1920, p. 293), those which occur in the Kuttung Series are flows. The following field-observations support this conclusion:

The main pyroxene-andesite has been examined along forty miles of outcrop, and at no point in that distance has any evidence of contact-metamorphism or transgression been observed at its upper surface. Typically the top of the flow makes poor outcrop. This is due both to contemporaneous weathering of the andesite and to the absence of any contact hardening in the overlying sediments.

In portion 180, Parish of Evan, near the head of Currabubula Creek, fine tuffaceous shales may be seen overlying the eroded and deeply weathered surface of the flow. A similar exposure occurs on the bank of Currabubula Creek near "Woodlands" homestead. A leached kaolinitic zone was found above the andesite in portion 104, Parish of Currabubula.

Tuff-breccias are developed at the upper surface in many places. Thus in a small gully in portion 258 in the Parish of Currabubula angular blocks of coarse andesite are embedded in a mixture of finer-grained lava and andesitic tuff. In Gaspard Creek near Wallabadah, where the andesite is well developed, it seems to be composed of one thick initial intrusion followed by a series of thin flows which pass into flow-breccias. Similar evidence has been seen in all the masses of the higher andesite horizon, e.g., in portion 247, Parish of Werrie, in the Kingsmill's Peak mass. Associated with the tuff-breccia there are occasional amygdaloidal and scoriaceous phases; these features are most marked where the flow is thin, as in the tongue where the Duri Peak mass is wedging out. In a sill a thin extremity of this kind, instead of being scoriaceous and amygdaloidal with abundant cavities, would be very fine-grained and compact. Also where vesicular phases are developed, they are found at the upper surface, not in the middle as they would be in the case of a sill.

Fluxional banding with development of spherulites is quite a common feature on both horizons. Pebbles of pyroxene-andesite occur in some of the Lower Kuttung conglomerates.

The important factor which led Professor Benson to regard the andesite as intrusive was its lithological resemblance to the proved sills in the Burindi Series. However, apart from the similarity of rock-type, there is considerable divergence of characters in the field. Evidence of contact-metamorphism is quite common above the sills, and where their outcrop wedges out the line is carried on for long distances by zones of silicification and quartz reefs, indicating that the intrusion persists at a shallow depth. Furthermore, when the sills are carefully mapped, it is found that their horizon in the Burindi Series is not constant and in places they are markedly transgressive. The flows in the Kuttung Series on the other hand are persistent in their horizons, and never transgressive.

In view of all the field-facts, the extrusive character of the Kuttung andesites of the Werrie Basin is placed beyond question, and this region is brought into harmony with the other parts of the State.

Relation of Lithoidal and Glassy Andesites.

The relation of the stony and glassy phases of the Kuttung andesites has been the subject of some discussion (see Osborne, 1925, pp. 116-119). Professor Browne, in his survey of Palaeozoic igneous action in New South Wales (1929, p. xxviii) wrote: "Another matter that has yet to be cleared up is the relationship of the glassy and stony types of andesite. Some lines of evidence tend to show that they are separate and distinct phases, while on other grounds it would appear that devitrification or some such process has been responsible for the conversion of glassy into stony types."

In this connection the field-relations of the two phases in the Werrie Basin suggest that the glassy andesite merely represents the rapidly-cooled portion of the flow. The base of the flow is usually glassy and prismatic; this passes up into a banded zone, where there is an interlamination of the vitrophyric and lithoidal phases. The bands vary in thickness from a fraction of an inch to a foot or more. Such types may be seen at many places along the scarps of the andesite cuesta-line north-east of Currabubula. The lamination may have been caused by the mixing and streaking out of the hotter and cooler parts of the magma during extrusion. Near the centre of the mass there would be sufficient time for the equalization of the heat before solidification, but at the margins the rapid congelation of the already cooled layers would form glass, while the hotter layers would show rudimentary crystallization.

Similar banding is found also at the top of the flow, where fluxional contortions are common in the banded rock.

A variant of this phase is found on the upper surface of the Duri Peak flow, where selective bands are packed with small spherulites up to an inch in diameter. On the Royston section the upper surface of the main andesite shows numerous large spherulites of the lithoidal phase embedded in the glassy andesite. Similar spherulitic structures are to be seen in the bed of Werrie's Creek in portion 172, Parish of Werrie.

On the interpretation outlined here, the stony phases were cryptocrystalline *ab initio* and are not, as a general rule, a product of the devitrification of the glassy phases. This view, based on field-evidence, is in agreement with the results of Osborne's microscopic analysis (1925, p. 118).

5. Sequence of Physiographic Expression.

The Werrie Basin is a region in which topography has been able to adjust itself more or less completely to rock structure. Differential erosion has attained equilibrium and there is scarcely a hill whose form is not obviously due to its local geological association. The Werrie basalts, the softest strata, have everywhere reached their base-level and form open plains between the mountains and ridges of the Upper Kuttung and Warrigundi rocks. Other soft groups such as the Burindi and Barraba beds and the Lower Kuttung tuffs approximate perfectly to this peneplaned condition, and form long strike-valleys.

Each stratum then, has a physiographic index which depends partly on its own resistance to chemical and mechanical disintegration and partly on its association in the sequence with other weak or strong beds which will expose it to or protect it from the agents of denudation.

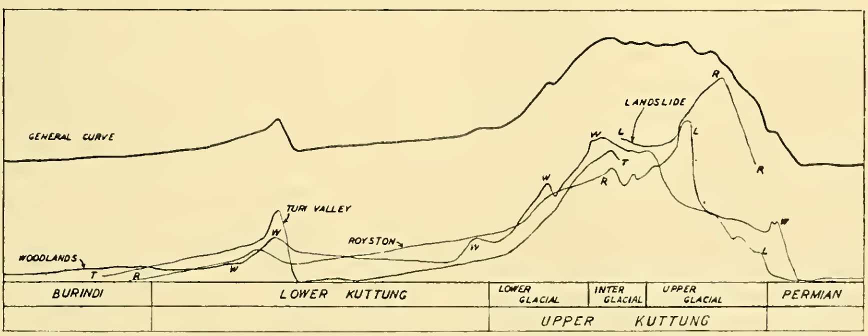
A set of graphs (Text-fig. 5) has been constructed to illustrate the sequence of physiographic expression in the Werrie Basin. A profile-graph has been drawn for each of the stratigraphical sections, using the average thickness of each bed as abscissa and twice the elevation of the outcrop of that particular bed on the section-line as ordinate. In each case the datum from which the elevation was measured was the lowest point on the section. It was necessary to use the average thickness of the bed in order that the profiles might be directly compared. The resulting graph is equivalent to the profile which the beds would give if they were dipping vertically.

The general similarity of all the curves is at once apparent. The plain of the Werrie basalts, the lowlands of the Lower Kuttung and Burindi Series, and the mountain range of the Upper Kuttung are common to all the graphs.

They are not precisely similar, however. They are similar only in so far as their stratigraphical sequence is similar, for the differences between the curves are directly related to lateral variations in the sequence.

Thus the differences on horizons (6) and (7) are due to variations in the thickness of the pyroxene-andesite flow and the boulder beds beneath it. The Turi Valley section is the nearest approach to the average for the Werrie Basin for this horizon.

The crest on the Woodlands curve at horizon (10) is due to the development there of the upper zone of pyroxene-andesite. Duri Peak or Kingsmill Peak sections would show lofty cuestas at this point. The trough on the same section, however, above horizon (14) is due merely to the way the section cut the local drainage; a line a little to the south of the section would have avoided this gully. Sufficient numbers of sections would eliminate all such local irregularities from the general curve compounded from them.



Text-fig. 5.—Sequence of Physiographical Expression in the Werrie Basin.

The high eminence developed on the Royston curve at horizon (24) is due solely to the great thickness of acid lava which forms the Piallaway Trig. station ridge, and which is absent from the other sections.

The Woodlands section is the only one which includes the Lower Coal Measures, which accordingly express themselves on the graph. The gradients LL and RR are normal where the Lower Coal Measures are overlapped.

The general curve was constructed by averaging the individual profiles. The ordinate for each horizon is an approximation of its physiographic index.

The conspicuous features of the general curve are the main range of the Upper Kuttung, the downs of the Lower Kuttung and Burindi, the ridge-line of the main pyroxene-andesite, and the Werrie basalt plains.

As was pointed out above, this curve represents the strata as dipping vertically. With the usual dips in the Werrie region the main pyroxene-andesite forms a beautiful line of cuestas. From the top of Kingsmill's Peak it is a most inspiring sight to look along this splendid row of cuesta-tops, extending for twenty-five miles in an unbroken line, each dressed against its neighbour, with their sweeping dip-slopes losing themselves one behind the other in the valley beneath. From the same lookout one can view the rolling lowlands of the Lower Kuttung, between the cuesta-line on the east and the bluff scarps of the Upper Kuttung on the west. Several divides belonging to the transverse drainage cross this valley, but never do they attain sufficient prominence to break its continuity.

With the prevailing moderate dips the Upper Kuttung forms a high double or triple cuesta. The lower part of the Interglacial Stage usually overhangs the Lower Glacial beds along a line of cliffs, but the upper part recedes some distance down the dip-slope, forming a longitudinal col between the crest of the clastics and the scarp of the Upper Glacials. The triple form to the range is usually due to the presence of the hard conglomerates of the Lower Coal Measures, which rise above the underlying varves.

The Werrie Basalt plain is responsible for all the lowland between Quirindi, Currabubula and Piallaway, as well as the Breeza Plains. In the whole of the Werrie basalt area there is not a hill which does not owe its presence either to an intrusion of Warrigundi rock, or an outlier of the Upper Coal Measures.

There is a direct relation, too, between the physiographic curve and the agricultural use to which the land has been put. For example, the mountain country of the Upper Kuttung is invariably barren and carries a very miserable stunted tree-growth, which is rarely cleared. In about forty square miles of Upper Kuttung country in the Werrie Basin region there is not a single cultivation paddock.

The downs of the Lower Kuttung, on the other hand, are always cleared and dotted with homesteads. They provide good pastures and scattered small wheat-paddocks. Access is always easy along the strike, for even though the drainage is usually transverse, with long subsequent tributaries, the lateral divides within the Lower Kuttung are low. A fine example of this rolling grazing country with wheat-farms on the flatter parts, follows the belt of Lower Kuttung rocks between Duri Peak and Kingsmill Peak, and carries on beyond across the open headwater tracts of Coeypolly and Jacob and Joseph Creeks to Wallabadah. A similar Lower Kuttung belt of grazing downs with small areas suitable for cultivation extends through "Royston" and "Merlewood", taking in "Glenoak" and the Oakey Creek paddock of Piallaway Station. Between Duri Peak and Somerton the main pyroxene-andesite cuts out, so the Lower Kuttung belt merges into the wheat-fields of the Burindi Series, and is extensively cultivated.

This narrow Lower Kuttung belt then, from Piallaway via Somerton and Duri Peak to Wallabadah, is an agricultural unit which contrasts strongly with the barren Upper Kuttung ridge-country which overhangs it.

The Burindi and Barraba Series are very suitable, both physiographically and in the soil they have yielded in this climatic environment, for agricultural purposes, and they are extensively cultivated. A continuous wheat-belt follows these rocks from Somerton to the boundaries of the Goonoo Goonoo estate.

References.

BENSON, W. N., 1920.—The Geology and Petrology of the Great Serpentine Belt of New South Wales. Part IX. The Currabubula District. PROC. LINN. SOC. N.S.W., xlv (2), p. 285.

————, 1921.—A Census and Index of the Lower Carboniferous Burindi Fauna. *Rec. Geol. Surv. N.S.W.*, x (1), pp. 12-72.

BENSON, W. N., and SMITH, S., 1923.—On Some Rugose Corals from the Burindi Series (Lower Carboniferous) of New South Wales. *Q.J.G.S.*, lxxix, 1923, p. 161, footnote.

BROWNE, W. R., 1920.—The Geology and Petrology of the Great Serpentine Belt of New South Wales. Part IX, Section C, Petrology. PROC. LINN. SOC. N.S.W., xlv (3), pp. 405-423.

————, 1926.—The Geology of the Gosforth District. *Journ. Roy. Soc. N.S.W.*, lx, p. 213.

————, 1929.—An Outline of the History of Igneous Action in New South Wales till the Close of the Palaeozoic Era. PROC. LINN. SOC. N.S.W., liv, 1929.

CAMBAGE, R. H., 1912.—*Journ. Roy. Soc. N.S.W.*, xlvi, 1912, p. xxiv.

CAREY, S. W., 1934*a*.—The Geological Structure of the Werrie Basin. PROC. LINN. SOC. N.S.W., lix, p. 351.

————, 1934*b*.—Note on the Implications of the Irregular Strike-lines of the Mooki Thrust System. *Ibid.*, p. 375.

————, 1934*c*.—Report on the Geology of the Myall Lakes Region. *Science Journal, Sydney University*, 13 (3), p. 42.

————, 1935.—Note on the Permian Sequence in the Werrie Basin. PROC. LINN. SOC. N.S.W., lx, (5-6), p. 447.

COLEMAN, A. P., 1908.—Glacial Periods and their Bearing on Geological Theories. *Bull. Geol. Soc. Amer.*, xix, pp. 347-366.

DAVID, T. W. E., 1932.—Explanatory Notes to Accompany a New Geological Map of the Commonwealth of Australia. *Sydney.*

DUN, W. S., and BENSON, W. N., 1920.—The Geology and Petrology of the Great Serpentine Belt of New South Wales, Part IX, Section B, Palaeontology. PROC. LINN. SOC. N.S.W., xlv (3), p. 336.

ETHERIDGE, R., 1900.—Corals from the Coral Limestone of Lion Creek, Stanwell, Queensland. *Bull. Geol. Surv. Queensland*, No. 12, 1900.

GRABAU, A. W., 1924.—Principles of Stratigraphy. *New York.*

————, and SHIMER, H. W., 1909.—North American Index Fossils. Vol. I, pp. 58, 386. *New York.*

HILL, DOROTHY, 1934.—The Lower Carboniferous Corals of Australia. *Proc. Roy. Soc. Queensland*, xlv (12), 1934, pp. 63-115.

HUNTINGTON, E., 1907.—Some Characteristics of the Glacial Period in Non-Glaciated Regions. *Bull. Geol. Soc. Amer.*, xviii, p. 351.

LLOYD, A. C., 1934.—Geology of the Gunnedah and Manilla Districts. *Ann. Rept. Dept. Mines N.S.W. for 1933*, p. 89.

OSBORNE, G. D., 1922.—The Geology and Petrography of the Clarencetown-Paterson Districts, N.S.W., Parts 1 and 2. PROC. LINN. SOC. N.S.W., xlvii.

————, 1925.—*Idem*, Parts 3 and 4. *Ibid.*, Vol. l.

————, 1926.—Geology of the Carboniferous Rocks in the Mt. Mirannie and Mt. Dyrring Districts. *Ibid.*, li.

————, 1927.—The Carboniferous Rocks in the Muswellbrook-Scone Area. *Ibid.*, lii.

————, 1929.—Some Aspects of the Structural Geology of the Carboniferous Rocks in the Hunter River District between Raymond Terrace and Scone. *Ibid.*, liv (4), p. 436.

REID, J. H., 1930.—The Queensland Upper Palaeozoic Succession. *Queensland Geol. Surv. Pub.*, 278.

SCHMIDT, H., 1923.—Zwei Cephalopodenfaunen an der Devon-Carbongrenze im Sauerland. *Jahrb. Preuss. Geol. Landesanstalt, Berlin*, xliv, 1923, 153.

SUSSMILCH, C. A., 1935.—The Carboniferous Period in Eastern Australia. Presidential Address, Sect. C, *A.N.Z.A.A.S.*, Melbourne.

————, CLARK, W. M., and GREIG, W. A., 1928.—The Geology of Port Stephens. *Journ. Roy. Soc. N.S.W.*, lxii.

————, and DAVID, T. W. E., 1919.—Sequence, Glaciation and Correlation of the Carboniferous of the Hunter River District. *Journ. Roy. Soc. N.S.W.*, liii.

————, ————, 1931.—The Upper Palaeozoic Glaciations of Australia. *Bull. Geol. Soc. Amer.*, xlii.

TWENHOFEL, W. H., 1936.—Marine Unconformities, Marine Conglomerates and Thickness of Strata. *Bull. Amer. Assoc. Petr. Geol.*, xx, p. 6.

VOISEY, A. H., 1934.—Geology of the Middle North Coast District, N.S.W. PROC. LINN. SOC. N.S.W., lix.
WALKOM, A. B., 1935.—Some Fossil Seeds from the Upper Palaeozoic Rocks of the Werrie Basin, N.S.W. PROC. LINN. SOC. N.S.W., lx (5-6), p. 459.
WHITEHOUSE, F. W., 1930.—The Geology of Queensland. *Handbook of Queensland. A.N.Z.A.A.S.*, Brisbane Meeting.
WORTHEN, A. H., 1866.—Geological Survey of Illinois. Vol. ii, Palaeontology, p. 166.

EXPLANATION OF PLATE XVIII.

Geological Sketch-Map of the Babbinboon District.